Smart Car Technologies: A Comprehensive Study of the State of the Art with Analysis and Trends

by

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ABSTRACT

Driving is already a complex task that demands a varying level of cognitive and physical load. With the advancement in technology, the car has become a place for media consumption, a communications center and an interconnected workplace. The number of features in a car has also increased. As a result, the user interaction inside the car has become overcrowded and more complex. This has increased the amount of distraction while driving and has also increased the number of accidents due to distracted driving. This thesis focuses on the critical analysis of today's in-car environment covering two main aspects, Multi Modal Interaction (MMI), and Advanced Driver Assistance Systems (ADAS), to minimize the distraction. It also provides deep market research on future trends in the smart car technology. After careful analysis, it was observed that an infotainment screen cluttered with lots of small icons, a center stack with a plethora of small buttons and a poor Voice Recognition (VR) results in high cognitive load, and these are the reasons for the increased driver distraction. Though the VR has become a standard technology, the current state of technology is focused on features oriented design and a sales driven approach. Most of the automotive manufacturers are focusing on making the VR better but attaining perfection in VR is not the answer as there are inherent challenges and limitations in respect to the in-car environment and cognitive load. Accordingly, the research proposed a novel in-car interaction design solution: Multi-Modal Interaction (MMI). The MMI is a new term when used in the context of vehicles, but it is widely used in human-human interaction. The approach offers a non-intrusive alternative to the driver to interact with the features in the car. With the focus on user-centered design, the MMI and ADAS can potentially help to reduce the distraction. To support the discussion, an experiment was conducted to benchmark a minimalist UI design. An engineering based method was used to test and measure distraction of four different UIs with varying numbers of icons and screen sizes. Lastly, in order to compete with the market, the basic features that are provided by all the other competitors cannot be eliminated, but the hard work can be done to improve the HCaI and to make driving safer.

DEDICATIONS

I would like to dedicate this work to my grandmother SAMJUBEN NAKRANI, my parents KESHUBHAI NAKRANI and PARVATIBEN K.NAKRANI, my brother SANJAY NAKRANI, my whole joint family, relatives and friends back in India for their extended support.

These are the people who deserve the credits for all I am at present.

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LIST OF ACRONYMS

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
CS	Center-Stack
DAS	Driver Assistance System
EBA	Emergency Breaking Assist
DOT	Department of Transportation
GPS	Global Positioning System
HCD	Human Centered Design
HCI	Human Computer Interaction
HCaI	Human Car Iteration
HUD	Heads up Display
IC	Instrument Cluster
IEEE	Institute of Electrical and Electronics Engineers
IVI	In-car Voice Interaction
IVIS	In-car Voice Interaction System
ISO	International Organization for Standardization
ITS	Intelligent Transport Systems and Services
ITU	International Telecommunication Union
LCAS	Lane Change Assistance System
LDWS	Lane Departure Warning System
LIDAR	Light Detection and Ranging
LTE	Long-Term Evolution
MMI	Multi Modal Interaction
MMIS	Multi Modal Interaction System

NHTSA	National Highway Traffic safety administration
NVS	Night Vision System
OEM	Original Equipment Manufacturer
PAS	Parking Assistance System
PDS	Pedestrian Detection System
PDA	Personal Digital Assistant
POI	Point of Interest
SAE	Society for Automotive Engineers
SR	Speech Recognition
SW	Steering Wheel
TLRS	Traffic Light Recognition System
TSRS	Traffic Sign Recognition System
VR	Voice Recognition
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle

CHAPTER 1

1. INTRODUCTION

This chapter provides an introduction to the Human-Car Interaction (HCaI) and its distinction from Human-Computer Interaction (HCI). It introduces the Advanced Driver Assistance Systems (ADAS) and the scope of this thesis. It also covers a list of the contributions and the flow of this thesis.

1.1 Overview

The technology inside the car is moving at considerable pace from simple Driving Assistance Systems (DAS) to Advanced Driver Assistance Systems (ADAS) and from the simple mechanical cockpit to an interactive connected cockpit. A Few years ago, choosing a new car was relatively straightforward. After cost, and possibly color for some, primary concerns were things like engine size, performance and fuel efficiency. Over time, cars have matured to be more comprehensive and software oriented as more cars are connected to the internet either through direct in-vehicle dashboard controls or through the existing data coupled via the driver's personal devices. Today, car manufacturers are making our selections more difficult by adding all means of the advanced tech features. Innovations and changes have become an inevitable part of the automotive industry. The revolution has set the stage to the extent that the manufacturers are not thinking about "Why do we need a Smart Car?" but to "How could we deliver a Smart Car?" Most Original Equipment Manufacturers (OEMs) are now involved in one form or another with the smart car concept. OEMs need perceptibility on how to make the infotainment system easier to use, empower a platform for the future services, line up with industry regulations and make the smart car experience impeccable to the consumer.

Automakers are developing a variety of new technologies that will make cars far more digitally functional and smart than they are now, including high-resolution touch screen display, 4G LTE internet access, Wi-Fi, built-in satellite navigation systems, voice recognition systems, safety systems like driver assistance devices, etc. While these systems can indisputably improve the driving experience, there are fears they may also be too distracting for drivers, and making roads more dangerous as a result.

In the competition for providing more and more features with connected user experience, the main focus of developing the user interaction inside the car could worsen. No matter how appealing it might be to include more and more functionalities in the car to enrich the driving experience and its fun factor, the primary task of "driving" should never be placed out of the focus or should never make a trade-off to a highly interactive, technologically advanced cockpit. Most additional tasks on top of the primary task create cognitive load; some tasks are "cognitive overload" by requiring too much consideration from the driver, and others are "cognitive underload" by taking over parts of the driving tasks [NHTSA 2006]. Both types of tasks are highly likely to decrease the driver's attention to the environment and focus on the driving. Being engaged in additional tasks which are not related to driving is the main reason for the car accidents. Therefore, it is vital to consider "reducing the driver distraction" a general principle while developing user interfaces for the human-Car Interaction (HCaI).

As a part of an EcoCAR 3 project, I worked in the innovation team. The project was sponsored by the U.S department of energy (DOE) and General Motors and the aim was to redesign the in-car interaction of the 2020 Chevrolet Camaro and also keep driver distraction to a minimum. The EcoCAR 3 project is a four-year competition in which 16 different teams from across the United States are participating to build the hybrid electric version of the muscle car, Chevrolet Camaro. Arizona State University (ASU) is being one of the 16 participating teams; this work was done as a part of an innovation team at ASU. The extension of the work is carried out by another team member.

1.2 Smart Car Technology

The past few years have been an essential period, both in terms of the pace of innovation and improved consumer awareness of the connected car technology. From in-dash infotainment to heads up display (HUD), from touch interfaces to voice interaction, technology continued to transform the automotive industry on the several fronts this year. Here are the five trends that could have the most significant impact into 2015 and beyond:

1.2.1 Infotainment Outsourcing a Sale Point

Over the past few years, major automakers have marketed their app integration and development programs while at the same time struggling with the user interface and compatibility issues and how to preserve differentiation within the center stack. Center stack is occupied with traditional manual knobs along with a computer like touch display having software overloaded with a lot of functionalities. It was publicized in the first half of 2014 that most automakers would adopt Apple CarPlay (Apple's software for iPhone screen integration to the in-car infotainment) and Android Auto (Google's android OS platform for android phone screen integration to in-car infotainment). It was also said that the two tech giants would manage infotainment and also govern the data coming from potentially millions of in-car systems. This extends the tech companies' accustomed mobile platforms and features into the car and would positively provide relief to the car owners irritated with automakers' own problematic infotainment efforts.

1.2.2 Advanced Driver Assistance Systems (ADAS) Become Mainstream

Currently, if you check out most TV car commercials, you could notice the emergence of ADAS being promoted as one of the key features. A recent study by Compass Intelligence pointed out that safety preferences trump infotainment among consumers shopping for the new cars [Compass Intelligence 2014]. Also, driver assistant technologies were once found only on the high-end cars or at upper trim levels; features, such as blind-spot warning and forward collision prevention are becoming more common in a wide range of vehicles and a key purchase consideration among consumers. This explosion of ADAS also overlays the path to autonomous technologies and prepares drivers for the future in which machines take over to make driving safer and less demanding.

1.2.3 Proliferation and Promotion of the In-car Voice Recognition Systems

Drivers have started using their personal devices even inside the car, such as smartphones, tablets, and MP3 players and deadly distractions are almost always at arms-reach within the car. As regulators are worried about distracted driving, have called for bans on using hand-held devices behind the wheel. With that comes a need to empower drivers with a safer and a smarter way to engage with those systems otherwise drivers cannot take full advantage of what’s possible for today’s smart cars. Voice recognition system could potentially help in reducing such physical distraction. So, automakers have rushed to adopt voice recognition systems. The automakers are working hard to balance the demands of their consumers and bring connectivity and content into the car without bringing in added distractions. The voice recognition feature inside the car has become an important sell point for automakers. It's already hard to find a new luxury vehicle that does not have the voice recognition technology, and AAA predicts a five-fold jump in infotainment systems in new cars in the next five years. Also, a survey statistics estimates the share of the voice recognition system equipped cars is expected to increase from 37 percent in 2012 to 55 percent in 2019 [Statista 2015b].

1.2.4 Powerful Graphics Processing Goes Mainstream

People would surely expect luxury automakers, such as BMW, Mercedes, Ferrari, and Audi to offer rich graphic processing and sophisticated in-dash displays but when Honda announced that it would include NVIDIA's latest Tegra mobile processor in Honda Connect systems, it marked a turning point for the powerful visual computing capability being featured in mainstream vehicles. Honda has introduced the high definition graphic processor in the 2015 Civic, Civic Tourer and CR-V in Europe. As cars become more tech-laden, high-definition displays allow for an extended customization and reduced driver distraction, and this new phase of the cutting-edge cockpit development will likely continue to trickle down to lower-priced vehicles in 2015 and beyond.

1.2.5 Tackling Driver Data Privacy

In the past few years, widely adopted In-Car Voice Interaction Systems (IVIS) and ADAS is collecting massive data, a serious concern is growing about data privacy inside and outside of the car. A group comprising of the most automakers, selling vehicles in the U.S. published a set of Privacy Principles in November, 2014 that promises to safeguard driver data [Global Automakers 2014]. The principles are a pre-emptive move to keep the government from pushing in place regulations that are too rigid. Although some felt that they were too broad, this effort to create standards for the data privacy management serves as a respectable model for automotive and technology industry self-regulation and is the correct step towards tackling what would gradually turn into a hot button issues in the years ahead as cars amass more personal data on drivers.

1.3 Today's Car: A Computer on Wheels

Today, most of the devices are computerized; the car is no longer just the mechanical device made up of mechanical parts, and rather it has become a computer on wheels. As given below, the car runs on the computer software from design to manufacturing to the runtime.

1.3.1 Design and Modeling Time

Currently, most of the fancy designs of the cars are made with the use of computer software. It uses sophisticated computer software like AutoCAD design tool (A commercial software application for 2D and 3D computer-aided design-CAD) used for designing the car parts and 3D car models, Solid works for 3D designs (A CAD and a solid modeler, and utilizes a parametric feature-based approach to create models and assemblies in 3D), Siemens NX (As a design tool- parametric and direct solid/surface modelling, as an engineering analysis and modeling tool - Static, dynamic, electro-magnetic, thermal, using the Finite Element Method, and fluid using the finite volume method), Simulink , and LabVIEW.

1.3.2 Build Time (Manufacturing) Time

At the build time most of the car parts are tested for their performance using different software simulation tools, such as Simulink (developed by MathWorks, is a data flow graphical programming language tool for modeling, simulating and analyzing multi-domain dynamic systems) and LabVIEW (A system-design platform and development environment for a visual programming language from National Instruments), and data is collected to make sure best quality manufacturing. Moreover, assembling the parts to manufacture the car is done using computer automation such as a robot controlled assembly line. Even modern car manufacturers like Porsche and BMW have fully automated manufacturing plants with minimum man-power.

1.3.3 Runtime

This is the area of concern where the computer has most influence on the car. Most parts of the car, such as an engine, suspension, controls systems and car cockpit controls including infotainment and ADAS are monitored and controlled by computers. In this process, the Human-Car interaction (HCaI) has changed to Human-Computer Interaction (HCI). The current 7-Series BMW and S-class Mercedes claim to have about 300 processors each. Even a comparatively low-profile Volvo still has 50 to 60 baby processors on board. This states that a car has become a server running on the wheels.

1.3.4 HCaI vs HCI

Traditional Human-Car Interaction was fundamentally a driver only maneuvering a car at a given time and no other devices but the smart car experience has introduced lots of other devices like Wi-Fi connectivity, phone connectivity, external GPS, and many more. Technically, a driver is operating a car with one or more other devices at a time. First and foremost, the driving task can be divided into three classes: primary, secondary and tertiary [Geiser 1985]. Primary tasks describe how to maneuver the car, e.g. control the speed or check the distance to other cars or objects. The steering wheel, which is the most well-known primary controller, and the pedals are the earliest control devices introduced in the car. So far, these devices have stayed largely unaffected but the additional control shortcuts are often mounted on the modern-day steering wheels and that can be considered to be a fundamental part of the car. Secondary tasks are functions that increase the safety of the driver, the car, and the environment, e.g. setting turning signals, lane change warning, activating the windshield wipers. Tertiary tasks are all functions concerning entertainment and information system, e.g. playing music, using navigation maps, changing temperature of the AC. This thesis's main focus is on the analysis of human-car interaction in the secondary and tertiary task domain. In the end, the solution is proposed to enhance the interaction inside the car, named multi-modal interaction.

Even though the computing power of systems integrated with the car is analogous to current mobile phones or even desktop computers, interacting with these systems is very dissimilar. The HCaI is subjected to different constraints that generally do not apply to HCI [Kern, Schmidt 2009]. The comparison between these two is given in table1.1 below.

Table 1.1: Comparison between HCaI and HCI

Human-Car Interaction (HCaI)	Human-Computer Interaction (HCI)
-Every task has a precedence in the car: primary task, secondary task, tertiary task.	-There are not such restriction while interacting with computers.
-A driver has to share his attention between the primary task and other non-driving-related activities.	-User is able to provide his full attention to a computer system in a desktop environment
-Computer like input and output devices can't be used as it demands high attention mental as well as physical.	-Devices like mice, keyboards for an input and large information-rich displays for an output
-If driver doesn't pay full attention to the primary task, dangerous situation may arise.	-There are no such risk related to user's safety

-A driver is not free to choose body movements as he is buckled up in the driver's seat and is restricted in mobility.	-In a desktop environment, the user is more or less free to choose with which body part he wants to interact with the computer
-Two-handed operations are not acceptable; for the safety reasons, one hand should always remain on the steering wheel [European Communities 2007].	-The environmental conditions while using a desktop computer do not affect human computer interaction in a critical way.
-The HCaI is always used in context, where the current driving situation greatly affects the interaction. For example, interacting with an infotainment system under high traffic and noisy conditions might result in higher work load for the driver, be it physically, visually or mentally, than while driving on a silent and empty highway.	-A user might be disturbed by environmental noise or light conditions, but it is not known that this has ever put the user or others in his vicinity in a dangerous situation.
-In-car voice interaction has lost of the challenges regarding environment noise, hardware limitations and response time.	-There are no such limitations regarding noise or response time at home while interacting with computer on the voice recognition.
-The HCaI is also affected by outdoor environment use cases, such as engine noise, extreme sunlight or extreme dark, vibrations, snow, fog, and rain.	HCI mostly takes place in an indoor environment, which controlled and stable.

1.3.5 HCaI Differences in Context to User Profile/ Persona

There are also some dissimilarities in the development process of building new automotive user interfaces, which are not just due to the differences in interaction with computer systems in car versus in a desktop environment. Despite the fact that the applications for a desktop computer can be personalized to a specific target group and to an actual use case, user interfaces in cars have to be designed in a way such that a huge amount of the dissimilar users are capable to use it. The typical age of drivers ranges from 16 to over 80. Out of that the 80% of the 21year-old age group have a driver's license and that number stays on a similarly high level until the mid-70s age group [Green 2002]. Another user studies showed that drivers that are over 65 years old, need the time 1.5 to 2 times to perform a task than younger drivers [Green 2002]. This important fact has to be considered while designing new interfaces for the secondary or tertiary tasks in the car and also while assessing them. Other dissimilarities can be seen in the long development cycles because developing a new car model takes usually several years. That means a new user interface might be outdated before it actually becomes a real product. In comparison, the usual lifetime of a desktop applications is far more. This difference is even bigger when comparing the lifespan of a car to that of a PC or mobile phone. Furthermore, till date it was not easy to update the current version of automobile system like it is normally done for a desktop or a mobile phone applications.

Moreover, evaluating the usability of an automotive user interface consist of moral considerations, because the threat of an accident is always present. Although a trial-and-error methodology for evaluating a new user interface might be an option for a desktop application already on the market, this methodology is unacceptable for the automotive user interfaces, since it might have deadly consequences [Schmidt 2010]. Hence, it is essential to perform tests and studies first in a simulator in order to safely predict the effect of a new automotive user interface on the driving performance before taking the system on the road. Adopting new technologies, be it new of ADAS technology or the opportunity to have access to the internet and thereby to a huge amount of data, or voice recognition technology inside the car, could create new problems. Whether it is infotainment system or in-car voice recognition system, the information has to be presented in such a way that it does not overload the driver or distract the driver form the primary task of driving. In contrast, the shifting of many driving tasks to ADA could also lead to the driver being underloaded and allow drivers to shift their attention away from the road scene for a longer period to other activities in the car. Hence, the reactions to unpredictable events that involve the driver to override ADAS and take control of the primary task could be delayed.

1.4 Automotive Roadmap to 2030 & Beyond

Autonomous vehicle technology is still in its prototype stage. It is extensively being tested both inside and outside the automotive industry and is anticipated to have insightful impact on the ecosystem as well as bring unseen safety benefits, traffic flow and efficiency. It could also benefit the wider society and economy as driverless vehicles would enable the car as a service concept, transform the very notion of car ownership and the driving experience and the transportation of goods. This service offers a distinctive and holistic outlook on the entire automotive safety challenges covering the 4 phases of the automotive roadmap:

- Phase 1 - Passive Safety - Traditional telematics services like eCall (eCall is an initiative to bring rapid assistance to drivers involved in an accident anywhere in the European Union), bCall (bCall enables drivers to send out their location, automatically explore and report on the vehicle health metrics and pass this information automatically to a breakdown organization to ensure the fastest way of dealing with a breakdown), 911 call(Emergency call service in United States), remote diagnostics, and UBI (Usage Based

Insurance-type of insurance whereby the costs are dependent upon type of vehicle used, measured against time, distance, behavior and place) and cyber security protection.

- Phase 2 - Active Safety – ADAS features for an obstacle detection and a collision avoidance based on Radars, LIDARs (Light Detection and Ranging), camera, and sonar sensors.
- Phase 3 - Cooperative Safety – Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) applications based on DSRC (Dedicated Short-Range Communications are one-way or two-way short-range to medium-range wireless communication channels specifically designed for the automotive use), LTE (Long-Term Evolution, commonly marketed as 4G LTE, is a standard for the wireless communication of high-speed data for a mobile phones and data terminals), Satellite GPS (Global Positioning System directly connected to satellite for navigation and location based services), and other technologies.
- Phase 4 - Autonomous Vehicles – The final step for realizing the end goal of a zero accident environment combining latest cellular technologies (like app integration, car controls via mobile apps, car health, car diagnostic information, and safely and security alerts), V2I (Vehicle to Infrastructure communications, such as real-time traffic information, shorted possible rout, most economical rout considering traffic, and many more), and ADAS technologies.

The cars from German luxury brands, such as Mercedes-Benz, BMW, and Audi already cemented their way to Phase 2 and come with the key features of ADAS, such as front collision avoidance and lane changing systems. In addition to that, these players also offer innovative and sophisticated ADAS technologies, such as night vision, automatic park assist, and semi-autonomous driving systems.

How the cars are connected to their environment could change enormously over the coming years. Already a new driver assistance and safety systems can park the car autonomously, maintain a safe distance between cars at highway speeds, warn drivers of hazards ahead and even estimate and if necessary intervene in an emergency situations. Communications, entertainment, and so-called well-being technologies make driving more comfortable and enjoyable. Mobility and vehicle management systems provide real-time traffic information, optimal routing information and car's status information that helps the driver reach their destinations quicker, more reliably, and more efficiently.

Today, moving from the cars with ADAS to autonomous cars seems difficult due to the lack of the necessary infrastructure. Autonomous cars are what we see in our sci-fi dreams. Even if we love to drive, we're likely still fascinated by the likelihood of being able to sit back, relax, and do nothing when we're behind the wheel. If the sufficient infrastructure to support is available in the future, autonomous vehicles could be the future of the automotive industry. The only autonomous cars out there are still prototypes or test vehicles and they just aren't equipped for the road but we are heading in that direction. Boston Consulting Group (BCG) have made an unflinching prediction about how fast and just how thoroughly autonomous cars could take over the roads. Their estimations see these cars appearing on the road frequently by 2017 which is just 2 years away. Even more astounding, they see the global market for the autonomous cars striking $42 billion by 2025 [BCG 2015].The group came up with their numbers after taking into consideration interviews, meetings, and conferences with industry types, as well as surveys of consumers. They're also betting that the first markets to certainly go autonomous could be Japan and Western Europe. The tangle of the regulations involving cars in the United States (US) may make it little late is not so surprising.

The well-publicized efforts by companies like Google to build an operational autonomous vehicle have absorbed considerable attention on how the car of the future could look and function. Up till now, the assisted driving is the only one of the many new technologies and products automakers are integrating into the cars they build. It feels like something we'd want to try but not own any time soon. Figure 1.1 shows the prototype model of the google autonomous car.

Figure 1.1: Prototype of the Google-Autonomous-Car

1.5 General Definitions [NHTSA 2010]

- **Primary task** means driving related tasks like navigation, steering, and stabilization.
- **Secondary task** means blinking side lights or head lights, turn On/Off windshield vipers.
- **Tertiary task** means entertainment (radio, cd, etc.), communication (phone, internet, etc.), and comfort functions (air conditioning, seat positioning, seat belt, etc.), eating, drinking.
- **Driver's Field of View** means the forward view acquired directly through the windshield, rear, and side views acquired through the other vehicle windows, as well as the indirect side and rear views provided by the vehicle's mirrors.
- **Interaction** means an input by a driver to a device, either at the driver's initiative or as a response to displayed information. Interactions include control inputs and data inputs (information that a driver sends or receives from the device that is not intended to control the device). Depending on the type of task and the goal, interactions may be elementary or more complex. For this research interactions are restricted to physical, manual or visual actions.
- **Glance** means a single ocular fixation by a driver. If the eye glance characterization method being used cannot distinguish between different nearby locations of individual fixations, "glance" may also be used to refer to multiple fixations to a single area that are registered as one ocular fixation.
- **Glance Duration** means the time the gaze moves towards a target (the transition time) and the dwell time (the time fixated on a particular point) on the target. Glance duration does not include the transition time away from the target.
- **Lock Out** means the disabling of one or more functions or features of a device so that the related task cannot be performed by the driver while driving.

- **Manual Text Entry** means manually inputting individual alphanumeric characters into an electronic device. For the purposes of these Guidelines, digit-based phone dialing is not considered manual text entry.
- **Reading** means the driver's act of perceiving visually presented textual information. Reading does not include a driver's perception of auditory presented text.
- **Text-Based Messaging** means manually inputting individual alphanumeric characters into, or reading from, an electronic device for the purpose of present or future communication. This action includes, but is not limited to, the composition or reading of messages transmitted via short message service, e-mail, instant messaging service, internet-based messaging, or social media internet-based applications (including posting).
- **Infernal Distractions** means reading, selecting, or entering a phone number, an extension number, or voice-mail retrieval codes and commands into an electronic device for the purpose of initiating or receiving a phone call or using voice commands to initiate or receive a phone call.
- **Control Input** means a driver action to the human-machine interface of an electronic device that is intended to affect the state of that device. Control inputs may be initiated either by a driver or as a driver's response to displayed information initiated by a device.
- **Dependent Task** means a task that cannot be initiated until a prior task (the antecedent task) is first completed. The task's start state is thus dependent upon the end state of the antecedent task.

1.6 Scope and Research Methodology

The motive of the research presented in this thesis is to analyze and explore the smart cars, to point out the influence of the technology on the smart car interaction design, and to identify the technology trends to improve the interaction and minimize driver distraction. This also sheds light on the advanced driver assistance technologies that have influenced the in-car environment as well as prospects to support the human-centered design (HCD) process of novel automotive user interaction. There are ways to minimize driver distractions but this thesis focuses on the two. One is to improve the existing in-car interaction design. Another way is to provide advanced driver assistance in terms of making the driving task easier, more automated and safer. The first one serves the basis for the discussion on the interaction designs inside the car today. The interaction design is really crowded and feature-oriented rather than user-centered. The second one puts the question at what extent the driver should get assistance so that he is not (underloaded) completely careless and machine dependent. So to support the discussion, the types of the user interaction and their practicality for use while driving were analyzed in more details. The discussion in the work centers around the limited areas of the in-car environment which are the areas affecting the driver distraction. The areas of the in-car controls can be defined as instrument cluster, steering wheel, infotainment display, climate and media controls, car system controls, rear and front mirror controls, front passenger side auxiliary display controls, and real display controls. The scope of the work is given in the figure 1.2 below.

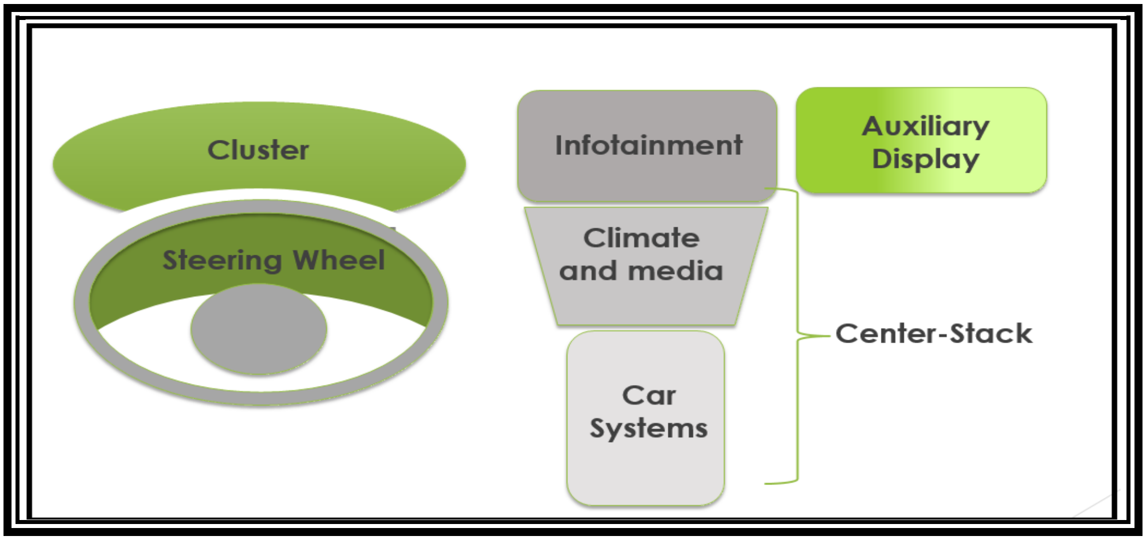


Figure 1.2: Project Scope of In-Car Environment

The main goal of the research was to come up with 2020 cockpit design for a muscle car "Chevrolet Camaro". When I started looking around to get some idea of what the interaction designs of other cars looks like, I realized that there's a big problem in current smart car interaction designs in term of driver distractions. So an innovation process was followed to propose a least distractive novel interaction design. First, started with 360 degree analysis: this includes exploring the current in-car technologies, such as in-car voice recognition, in-car telematics, and ADAS, also searching, collecting and analyzing about 400 photographs of car cockpits from different car models and different class like economy, premium, muscle, sports, and luxury. Second, competitor's analysis: it is the same as 360 analysis for the technology the competitors of Chevrolet Camaro to get an idea of what's the similarity and differences in the designs of the muscle cars. Third, close competitor's analysis: it includes close competitors of Chevrolet Camaro in the muscle car category in North American market. Fourth, remote competitor's analysis: includes the analysis of the remote market competitors of Chevrolet Camaro in the muscle category. Fifth, future trends analysis: Looked into future concept cars to identify the trends and get the idea of what kind of innovations are going in the domain. Finally, based on the extensive research, analysis and trends identified, proposed a futuristic interaction design to minimize the distraction at the same time providing a competitive solution with the same features and functionalities. To support the discussion, we conducted an experiment to benchmark a minimalist UI design. An engineering based method was used to test and measure distraction of four different UIs with varying numbers of icons and screen sizes. Furthermore, evaluation of the proposed idea (MMI) is conducted by another project mate with both quantitative and qualitative measures.

1.7 Contributions

The main contributions of this thesis are:

- ❖ Introduced a new term called Human Car Interaction (HCaI) in context to automotive use, which has a completely different set of challenges regarding interaction design, standards, and regulation to support the development of such a user interaction.
- ❖ Identified six major groups of interaction in the smart cars, combining the functionalities into these 6 major groups, and analyzing them based on the number of input buttons it requires to complete a task successfully.
- ❖ Conducted rigorous analysis of the in-car environment of 38 car models from the major automakers in the market, including the analysis of the in-car voice interaction and ADAS, and its impact on the driver distraction.
- ❖ Provided 284 analysis points addressing the issue of the in-car interaction design, with the main focus on the impact of the number of input buttons (a total of hard and soft buttons) on the driver distraction. For quantifying the interaction complexity in the center-stack, we devised metrics to measure the complexity.

- ❖ Proposed a minimalist interaction design concept, Multi-Modal Interaction (MMI) system in context to automotive use. Presented a prototype of the MMI system design to support the development of the least distractive UI’s for the HCaI.
- ❖ Conducted the experiment to benchmark an abstract screen layout of in-car user interface (UI), to measure the effects of screen size and number of icons on driver distraction and to evaluate the effects of our minimalist design on the driver distraction. The experiment results confirmed the complexity of interaction with the UI having more icons (soft buttons) and its impact on the driver distraction. The experiment results provide the guidelines to develop a simpler and minimalistic UI with fewer icons (soft buttons) to minimize the driver distraction.

1.8 Thesis Flow

Chapter 1 is the introduction to the trends in the automotive industry and general definitions used in the automotive interaction. It also define the important terms used, scope, contributions, and the flow of this thesis. Chapter 2 provides the historical overview of the automotive user interfaces and ADAS, the phenomenon of driver distraction is described, the challenges in the development of automotive UI, the guidelines and the norms are presented that may help to develop good automotive user interactions.

Chapter 3 introduces the voice recognition technology, presents the evolution of voice recognition systems, includes state of the art of the in-car voice interaction, provides current example of the in-car voice interaction systems in the automotive industry, and discusses the limitations of in-car voice interaction in terms of the driver distraction. Chapter 4 is about the innovation processes followed. It comprises of General domain review with competitors, close competitors, remote competitors, and future trends analysis. More comprehensive research and analysis of interaction design of the close competitors is given and the groupings of the functionalities is presented. It also proposes the method to quantify the interaction complexity in the center-stack. Chapter 5 focuses on the multimodality in automotive user interface, addresses the term "Multi-Modal Interaction" used in HCI and HHI, and proposes our enhanced multi-modal interaction in context to automotive application. Further, it describes the architecture and the different modes of interaction in detail.

Chapter 6 provides rigorous analysis of ADAS, discusses the impact ADAS on minimizing the driver distraction, and introduces the autonomous car technology, which are becoming the inherent part of the smart cars. Chapter 7 is about an experiment conducted to benchmark a minimalist UI design. It describes an engineering based method used to test and measure distraction of four different UIs with varying numbers of icons and screen sizes. Chapter 8 summarizes the results of the research and analysis done. It also summarizes the trends identified during the research and provide the directions for the future work. Lastly, it ends with conclusion.

CHAPTER 2

2. BACKGROUND AND RELATED WORK

This chapter starts with history of the automotive user interfaces and then explains how driver distraction has become a reason for major accidents. It also covers the challenges in designing the HCaI, guidelines and regulations for the HCaI designs.

2.1 Evolution of the Human-Car Interaction

If we look back, before 120 years the first motor vehicles were introduced by Gottlieb Daimler and Carl Benz in 1886. Since then it has been a continuous evolution not only in the terms mechanical function but also in the electrical and computing functions. At the beginning, the main focus was on providing a more or less comfortable, universal and individual means for transportation. Early cars only consisted of devices for the primary driving task (steering device and pedals). Since then the primary task has remained the same but what has change is the way of interaction in the car. Because of the integration of electronics and, more recently computers, into the HCaI (e.g. GPS, telematics, ADAS, and infotainment systems) have introduced new layers of complexity to interactivity, completely changing cognitive models and expectations. Car’s cockpit is getting more complex due to new, feature-rich assistance and infotainment systems on both built-in and nomadic devices [Kern, Schmidt 2009]. For this reason, there is an observable trend in the automotive systems where different functions are combined in an infotainment and entertainment systems, which usually consist of either a digital touchscreen or a single controller and a display and most recently in-car voice recognition. This trend of combining functions into a central system leads to a reduced number of different interaction devices but requires the driver to search through different menus to find a desired function. In some cases, this is not ideal, e.g. searching for the menu function that changes the radio volume might be annoying for the driver. Thus, there is a tradeoff between how many functions are quickly accessible and how overloaded the user interface is [Kern, Schmidt 2009]. This tradeoff can be observed in many current car interface designs. Figure 2.1 shows the physical evolution of cars cockpit from 1960 to 2014.

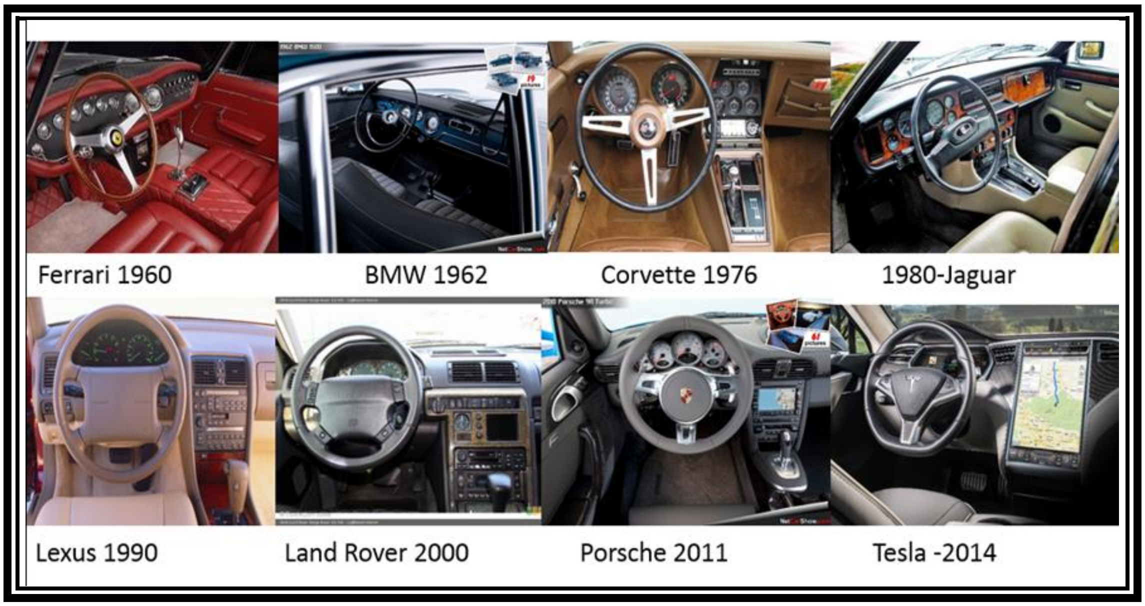


Figure 2.1: Physical Evolution of a Car Cockpit

If we look at the in-car environment today in term of the physical evolution, with increase in number of functionalities, there's an increase in number of small buttons and knobs. In addition to that, the smart car technology has added digital display as a mode of interaction. Firstly the displays used to be controlled by a bunch of manual buttons, and then touch displays started showing up in the center console.

These touch displays are nothing but the smaller version of a computer inside the car loaded with lots of small menus, icons, text, numbers etc. Secondly, the instrument cluster, which fully used to be the analog and the only functionalities it covered in the past were limited to speedometer, odometer, fuel status, and sometimes oil status, has also become digital and the infotainment functionalities, like music, radio, maps or navigation, have started appearing on the instrument panel.

Figure 2.2 illustrates the landscape of the in-car interaction today, it's mainly in the form of digital display in the center console as well as in the instrument cluster.

Figure 2.2: Landscape of the In-Car UI's today

However, in the haste to get on-trend, car manufacturers have simply used screens to replicate what has been before, rather than taking an empathetic, intelligent approach. Skeuomorphism abounds, where physical buttons are replaced with lookalikes on a screen familiarity is retained, but at the expense of tactile feedback. Current touchscreen HMIs are often simply ill-considered re-appropriated solutions developed for completely different contexts. Some of the automakers have completely replaced manual buttons in the center console with a big computer like touch display. For example, Tesla Model S 2014 comes with 18 inch big digital touch display in the center console. In Figure 2.3 below, if we see the comparison of Tesla versus the Boeing 757-300, it says a lot about the complexity and learnability of purely screen-based controls, such as those seen in the Tesla's center console [USTWO 2014].

Figure 2.3: Tesla Model S 2014 Cockpit Vs Boing 757 Cockpit

In last few years, the number of touch screen installations in the cars has exponentially increased. The figure 2.4 shows the statistic of the survey just come up in 2013 [Statista 2015c]. This statistic depicts the global number of touch screens installed in automobiles in 2011 and expected number of installation by 2019 in million units. Around 5.8 million units were installed in vehicles in 2011. This figure is anticipated to grow to over 35 million units in 2019. Furthermore, we are living in to a connected world where most of the devices are connected one or the other way. While driving, drivers also want to be connected to the outer world professionally as well as socially. So, beside the built-in connected devices, drivers bring a variety of the personal devices for info and entertainment into the car. Car manufacturers try to provide a means for integrating these nomadic devices physically, e.g. by providing Bluetooth interfaces, and virtually, by including external personal content like music playlists in their infotainment system. Many of the car functions have been made available in phone apps. For example providing functions to control cars with mobile phones, such as locking the car doors or getting the car systems status like oil change notifications.

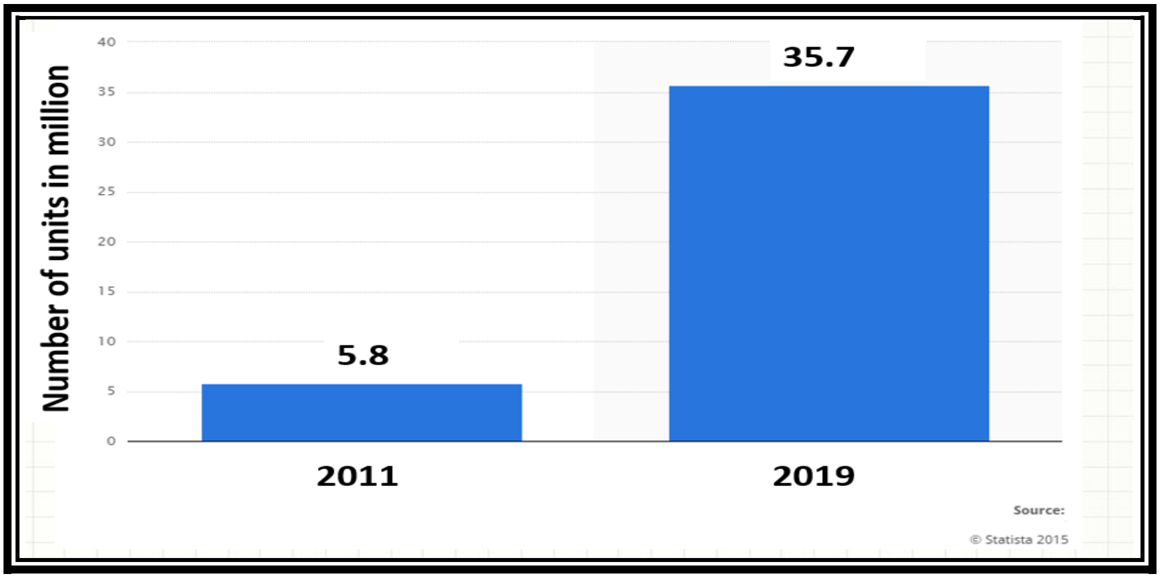


Figure 2.4: Touch Screens Installed in Cars Worldwide in 2011 and 2019

Lastly, voice interaction has also become one of the essential feature of the smart cars today. It was added as an alternative to manual or touch interaction with the motive to reduce the driver distraction but by the time voice interaction has also become complex in haste of providing more functionalities. There are also challenges regarding computing power, response time in case of the client server architecture and noise of the in-car environment. So what make the smart cars less distracting? In April 2013, the US National Highway Traffic Safety Administration (NHTSA is an agency of the Executive Branch of the U.S. government, is a part of the Department of Transportation-DOT, its mission is "Save lives, prevent injuries, reduce vehicle-related crashes") released voluntary guidelines on the subject for manufacturers, recommending that the systems must be designed in such way so that divers don't take their eyes off the road for more than two seconds at a time, or 12 seconds in a total per interaction or task [NHTHSA 2010]. The guidelines come after a study by the NHTSA, it showed that hand-eye coordination tasks (such as using a cell phone) made it three times more likely a driver would crash. Also, the researchers working in this field are well conscious that drivers want access to an increasing range of information, from navigation prompts to social media updates. Therefore stalling this information altogether is not convincing. If the in-car tech sealed the drivers out when vehicle in the motion, they would just pick up their phones. They always want to be and are going to be smart. The actual challenge is to comprehend how we can improve interfaces that balance demands, to find ideal ways for people to do these things.

2.2 Driver Distractions: A Problem and a Cause of Accidents

Over the 20 years from 1980 to 2000, the number of the licensed drivers in the U.S. increased 23.7%, from about 154.0 million to 190.6 million and again in next 11 years from 2000 to 2011 it reached 212 million. The total annual mileage traveled annually in the U.S. increased 28.9% from 1990 to 2000 and reached 2,767 billion miles in 2000 [DOT, 2000]. Driving is a very common activity for many people, making driving safe is a significant issue in daily life. Increased driver distraction has become one of the reasons for road accidents.

Distraction means the deviation of a driver's attention from activities other than primary task as defined in the section 1.5 (chapter 1 p.12). The primary tasks are critical for safe operation and control of a vehicle. According to the NHTSA research and guidelines published in April 2013, driver distraction can be classified in to four major categories [NHTSA 2010]. 1) Visual distraction, 2) Physical distraction, and 3) Cognitive distraction 4) Audio-Visual distraction. First three are covered in this section while the fourth one is discussed in chapter 3 in detail.

So far, it was known that only 14 % of accidents are likely to be caused due to distracted driving but according to new research published by the AAA Foundation for Traffic Safety on 25th March, 2015, distracted driving is much more severe problem than previously known [AAA 2015]. The AAA Foundation for Traffic Safety was founded in 1947 by AAA to conduct research to address growing highway safety issues. The organization’s mission is to identify traffic safety problems, foster research that seeks solutions and disseminate information and educational materials. The Foundation has funded over 250 projects designed to discover the causes of traffic crashes, prevent them, and minimize injuries when they do occur. Knowledge is the first step to becoming a better driver. The Foundation's studies have shown that understanding the risks of driving and one's own limitations can prevent crashes.

The unprecedented video analysis, in nearly 1700 videos of the teen drivers taken from in-vehicle event recorders, researchers at AAA finds that distraction was a factor in nearly 6 out of 10 moderate-to-severe teen crashes. The researchers investigated the six seconds of video leading up to a crash, the outcomes showed that distraction was a factor in 58 percent of all the crashes studied, comprising 89% of road-departure crashes and 76 % of rear-end crashes [AAA 2015]. The comprehensive analysis provides unquestionable evidence that the driver distraction is more than a serious problem.

2.2.1 Visual Distractions

Visual distraction means taking eye off the road and eyeing at something else either inside the car or outside the car. This category of the distraction is very common, as a driver it’s boring to keep gazing only on the road all the time but taking the eyes off the road for very long time is also very risky. The visual distraction mainly comprises of either secondary or tertiary task.

Visual distraction often happens while searching a functionality in the center console. The observations noted by in-vehicle equipment show that almost 80% of all crashes and 65% of all near-crashes involved the driver looking away from the roadway just prior to the event, [NHTSA 2006]. Nomadic device use and other distracted driving activities strongly related with teens looking away from the roadway, particularly females twice as likely as males to be using an electronic device, [AAA 2012]. Cognitive model suggests that the more we are acquainted with the interface and knowledgeable the less cognitive load it require to do the task related to that interface. It means the novice drivers are more inclined to dangerous distractions. A data collected from recording devices installed in participants' vehicles from 2003-04 (experienced drivers – average age 36.2) and 2006-08 (novice drivers – average age 16.4) measured the risk factor of actual crashes and near-crashes related to performance of the tasks including reaching for cell phone, dialing cell phone, talking on cell phone, texting, reaching for other objects, eating or drinking and adjusting vehicle controls. The tasks needful of drivers to look away from the road ahead, are noteworthy risk factors for crashes and near-crashes, mostly among novice drivers [Klauer 2014]. One more comprehensive survey done on the behavior and attitudes of teen, together with participation in distracted driving behaviors. It was broken down by daytime versus night time. 97% of teens have texted while driving during daytime and 47% at night, 92% when driving alone and 32% when driving with friends (suggesting perhaps social pressure may be reducing texting). The teens observed parents' driving distractions including hand held cell phone use 60%, hands-free cell phone use 46%, using navigation 40%, reading texts 29%, sending texts 25%; nearly 2/3 of teens viewed texting as unacceptable but 45% admitted to reading and 37% to sending texts [DOT 2011]. This shows that visual distraction has become even more inherent with the smart car technologies like navigation and hands-free calling.

2.2.2 Physical or Manual Distractions

Physical distraction means diversion or physical movement with one or both hands away from the steering wheel, and turning back or side. This category of distraction is most common and most often observed in-vehicle distraction. It includes task moving one or both the hands away from steer wheel for the different tertiary tasks, like texting while driving, manual operations like adjusting climate controls, media control, entering navigation address, eating, drinking, etc. or turning back or side to talk to other passenger in the vehicle or any other physical movement by the driver.

The major reason behind the most of distracted driving accident is due to physical or manual distractions. The percentage of driver's text-messaging or visibly operating hand-held devices increased from 1.3 percent in 2011 to 1.5 percent in 2012, the hand held cell phone usage continued to be higher among females, maximum among 16 to 24 year-olds and lowermost among drivers 70 and older [NHTSA 2014]. The NHTSA releases a survey on April, 2013. More than 6,000 participants of the age 16 and older were interviewed by phone for the National Survey on the Distracted Driving Attitudes and Behaviors. Almost half the drivers said they usually answer an incoming call and one in four drivers are willing to place a call on all, most, or some trips. Slightly smaller number are keen to make a call while driving compared to 2010 (28% to 24%), but there is a very little change in those who answer a call while driving (52% to 49%). Considering that in 2011, there were almost 212 million licensed drivers in the America, about 102 million drivers were answering calls and 50 million drivers were placing calls while driving [NHTSA 2013]. In 2011: 3,331 people killed in the accidents involving distracted driving and 387,000 injured, representing 10% of all deadly crashes and 17% of all accidents that caused damages; 12% of death toll involved the use of a cell phone (talking/listening to a cell phone, dialing/texting or other cell-phone-related activities); 5% of those wounded involved a cell-phone; for 15 – 19 year old drivers involved in deadly crashes, 21% were distracted by the use of a cell phone.[DOT 2010].

The nomadic devices, such as phone, tablet, and laptops are one of the biggest cause behind physical distraction and the accidents due to it. The cell phone distracted driving crashes "vastly under-reported" from the review of 180 fatal crashes from 2009 to 2011. Where evidence showed that the 52 % of crashes in 2011 involved driver using cellphone. In 2012, highway fatality rate increased for the first time in seven years; the data approximations that 25% of all the crashes involve cell phone use [NSC 2013]. Talking on a phone while driving seems routine but there are also other tasks while using phone such as checking status on the social media. According to a research, text messaging is associated with the highest levels of driving performance degradation and is more distracting than all other tasks due to its higher level of task demand (a combination of visual, physical and cognitive distractions) followed by destination entry while using map, and radio tuning is considered as the lowest levels of driving performance degradation. Also, the two phone dialing tasks, contact selection and 10 digit number dialing were comparable in their effects on the driving performance and were intermediate relative to the two extremes [NTHSA 2012].

One more related study by Federal Motor Carrier Safety Administration (FMCSA) exposed data about the increased possibility of crashing while engaged in specific tasks. Here X explains, how many times the probability of crashing increases by specific task : text messaging – 23 X, hunting through grocery bag – 10 X, writing on a pad or a notebook – 9 X, using calculator – 8 X, looking at a map – 7 X, phoning – 6 X, grooming – 4 X, reaching for object in vehicle – 3 X, [FMCSA 2009]. Lastly, a research concerning phone use discovered that those who use cell phones while driving more often are also likely to occupy in other driving behaviors that increase overall crash risk, including driving faster, changing lanes more often and hard braking [Zhao 2012 – 2013].

2.2.3 Cognitive Distraction

Cognitive distraction means mind occupied in more than one activity at a time other than focusing on the primary task of driving. For example, listening to radio, or listening voice mail, or more than one instruction from voice recognition system.

Distraction Model:-

Further we classified driver distraction in to four major category based on the cognitive model.

1) **Driving-Related Distractions – Internal:** Any activity performed by a driver as part of the safe operation and control of the vehicle, or any activity performed by a driver that relates to use of a vehicle system required by Federal or State law or regulation is considered as internal driving related distraction. For example tracking the speed of car, checking fuel, oil pressure, tire pressure, turning On/Off windshield wipers, lane change indicators, and headlights, etc.

2) **Driving-Related Distractions – External:** Any activity performed by a driver that supports the driver in performing the driving task but is not essential to the safe operation or control of the vehicle is external driving related distraction. For examples, keeping eye on the road, keeping eye on the vehicle ahead, keeping eye on the vehicle behind, keeping eye on the traffic singles, wipers, fog, rain, snow, keeping eyes on the road crossing pedestrians or vehicles etc.
3) **Non-Driving-Related Distractions- Internal:** Any activity performed by a driver other than those related to the driving task is considered as non-driving related internal distractions. For example plying radio, music, CD, etc., communication task like talking on a phone, texting, mailing, talking to other passenger in car, etc., comfort task like adjusting AC, internal lighting, seat adjustment, seatbelt adjustment, eating, drinking, etc.
4) **Non-Driving-Related Distractions- External:** Any activity performed by a driver other than keeping eye on the road outside the car, such as looking at advertisement boards, commercials, looking at other vehicles, rubbernecking, observing scenic views etc. are considered as non-driving related external distractions.

All four kind of distraction has led to very dangerous consequences at some point of time when combined with the other kind. The visual and physical distraction has been measured in a different research studies as we saw in the section 2.2.1 and 2.2.2 above. The cognitive distraction is the most difficult of the four sources of distraction to assess because of the problems associated with observing what a driver’s brain (as opposed to hands or eyes) is doing. Furthermore, changes in driving performance associated with cognitive distraction have been shown to be qualitatively different from those associated with visual distraction [Angell 2006 & Engström 2005]. For example, visual distraction has been shown to increase the variability of lane position, whereas cognitive distraction has been shown to decrease the variability of lane position [Cooper in press].But all the cognitive distractions are not bad. Some even keeps driver active in many ways. A related research about cognitive load was dome in 2011, Shutko and Tijerina reviewed a large naturalistic study of the infield operational tests on the cars, heavy product vehicles, and commercial vehicles and buses and concluded that:

- Most of the collisions and near misses that occur involve inattention as a contributing factor.
- Visual inattention (looking away from the road ahead) is the single most significant factor contributing to crash and near crash involvement.
- Cognitive distraction associated with listening to, or talking on a handheld or hands-free device is associated with crashes and near miss events to a lesser extent than is commonly believed, and such distractions may even enhance safety in some instances.

One key feature of the smart cars is voice recognition systems. In the last few years it has been promoted as a key feature reducing driver distraction and now many of the new cars come with voice recognition. After new speech-based in-vehicle technologies and infotainment systems proliferated, there were prevailing conventions that the "hands-free" = safe and 66% of people say use of hand-held devices by driver is unacceptable and 56% of driver say hands-free is acceptable. While the policymaker such as 14 state governments have banned texting while driving and use of handheld device inn car, and no one has banned the hands-free devices. Moreover, the automotive industry often market in-vehicle speech-based technologies and infotainment systems as safe by virtue of being hands-free.

The AAA Foundation for Traffic Safety set out in 2011 to study this common perception about hands-free devices and voice recognition and examined possible sources of the cognitive distractions for drivers. They did the evaluation of the two most common voice-based interactions in which drivers involve; changing radio stations and voice dialing. The evaluation was done with the real voice-activated systems found in six different automakers' vehicles.

The results of the study included:

- There are significant deficiencies to driving that stem from the digression of attention from the task of operating a motor vehicle, and that the deficiencies to driving are directly related to the cognitive workload of these in-vehicle activities.
- Moreover, compared to the other activities studied (e.g., listening to the radio, conversing with passengers, etc.) they found that interacting with the speech-to-text system was the most cognitively distracting. This clearly suggests that the adoption of the voice-based systems in the vehicle may have unintended consequences that adversely affect traffic safety.

2.3 Challenges in Automotive UI Design

Historically, car manufactures and their part suppliers developed user interfaces and the required devices, but now, many manufacturers and companies that provide software and nomadic devices have designed systems that would possible to use while driving. The need for providing standardized interfaces for connecting such devices to the car is increasing by the number of personal devices that drivers want to use while driving. Downloading apps from an app store to a mobile device is nowadays a common approach and it's also possible for the car as well. Finding a means for analyzing and documenting automotive user interfaces is a fundamental challenge, especially when considering the huge number of parties that are now involved in the development process. This means it should be applicable in all the stages of the design process. Particular attention is paid to the evaluation of the new automotive user interfaces. A main challenge for the development process of automotive user interfaces is to provide safe methods for qualitative as well as quantitative measures. These measures are needed to help decide if a novel user interface can be recommended for the use while driving when taking driver distraction into account. Another challenge is keeping up with the fast pace of software development and the apps culture. Rapid prototyping and quick evaluation methods are required to decide quickly which user interface idea is it worth pursuing and which idea would distract the driver too much from his primary task [Kern, Schmidt 2009].

From the beginning, cars were built in a way that not only the driver but also some passengers could be transported. That makes driving often a social event. On the one hand, the presence of passengers is recognized to increase driving safety by having an extra set of eyes and ears watching the road [Rueda-Domingo 2004]. On the other hand, passengers are perceived as the cause of distraction by giving the driver a motive to take his attention off the road [Lerner 2007]. Generally while driving with passengers, the driver is involved in a chat or discussion. A additional challenge for human-car interaction can be seen in providing entertainment for passengers and in supporting natural interaction between the driver and the passengers without taking the driver's attention off the road. As discussed in section 1.3.4 (p.6-7), the differences between human-computer interaction in the desktop or mobile devices domain and human-car interaction result in additional requirements for the design development process.

A human-centered design process for interactive systems is proposed in ISO 9241-210 [ISO 9241-210:2010]. Although the car context has different requirements in the design cycle steps, the car has become a computer-based interactive system as well. Figure 2.4 is modified version of Human-Centered Design (HCD) process according to ISO 9241-210 [ISO 9241-210:2010] proposed in [Kern, Schmidt 2009] with added specific requirements in context to automotive user interaction design. The green boxes at the specific activities indicate additional requirements for developing automotive user interaction.

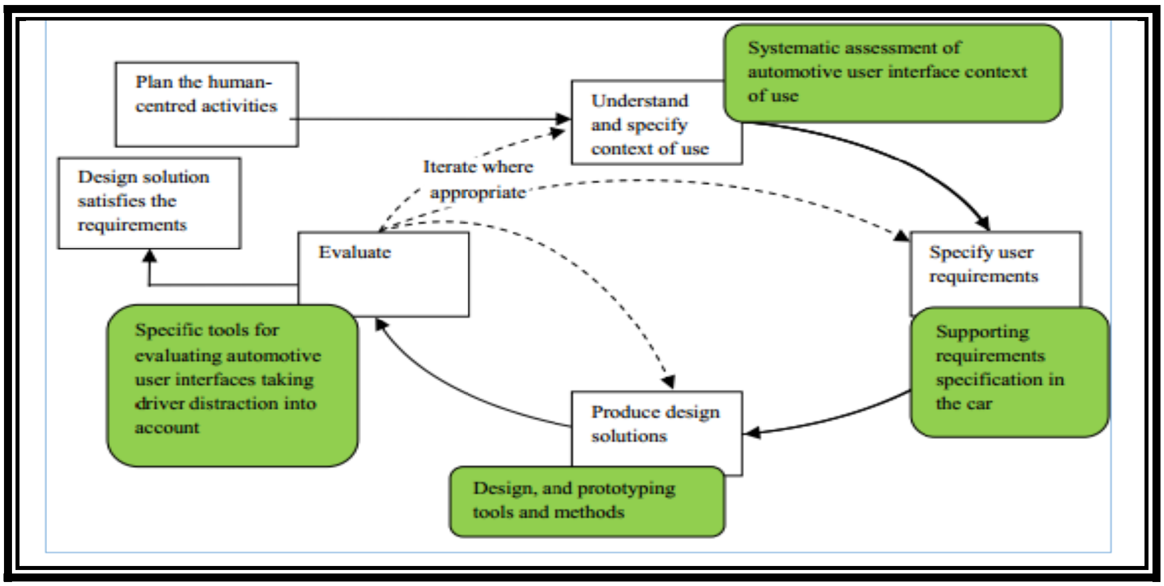


Figure 2.5: HCD Process- ISO 9241-210 Adapted into the Automotive Context

The key challenge for automotive user interfaces is to build them in a way that they do not negatively affect driving performance and enhance the driver's experience, it means ideally they would make driving safer but still provide a valuable service. Additionally, tools and methods are desirable to prove that new automotive user interfaces are appropriate for use while driving. Interacting instinctively and naturally is probably users' most preferred way of interacting with a computer. No training or handbooks are needed to use such an interface, and in the car context, such an interface helps to retain safety. User interaction designers exploit implicit interaction techniques to make interaction more natural. One challenge for automotive user interfaces is to assimilate new modalities into the car, e.g. eye tracking, gesture recognition, voice recognition, etc., which enables natural and inherent input to the system and thereby moderates the driver's cognitive load. With many new interaction technologies, designers have more and more options in creating user interaction.

In other areas, ranging from PCs to gaming devices and mobile phones, providing multi-modal user interfaces has aided to increase usability and enjoy capability of systems. User hopes have changed due to this and multimodal user interfaces should be accessible everywhere. Hence, in cars we see more and more hard work to offer new or alternative modalities, principally creating multimodal user interfaces but they are just interfaces not a real multi-modal interaction where user can switch in between any modes of interaction at any point of interaction. . Today's multi-modal interface offers multiple modes, such as touch, manuals, speech gesture, etc. but they works independently and we can't switch in-between naturally as we do naturally using a combination of senses. We can say, there's need of the enhanced multi-modal interaction as compared to existing ones. Design and development of such a multimodal interaction systems in the car is another principal challenge.

2.4 Guidelines for Automotive UI Design

Interaction principles and design guidelines play a significant role in developing user interfaces by regulating them and making user interaction with them more intuitive. Detailed guidelines and ISO standards that address the characteristics of the automotive user interfaces exist. This section introduces a few guidelines and norms. Different organizations across the world [AAM 2006; UN/ECE 1998; JAMA 2004; European

Communities 2007], established recommendations on how to design a safe and easy-to use automotive user interface. Moreover, they recommend how to design such systems to be used while driving. All of them target more or less for the same objectives. For example, the aims of [JAMA 2004] is summarized below:

- The system should retain the effect on safe driving to a minimum
- The visibility of forward field should not be blocked by the system
- Driver's attention should not be distracted from driving
- Operating the system should not affect the driver's primary task, driving

Furthermore, the guidelines are written for designers of the in-vehicle interaction systems that are factory-installed but can be partially applied to portable devices [European Communities 2007]. The recommendations are distributed in different sections conversing the following principles [AAM 2006; European Communities 2007; JAMA 2004]:

- Installation principles, e.g. how to place displays and controls to guarantee mapping.
- Interaction with displays and controls, e.g. at least one hand should keep on the steering wheel.
- Information presentation principles, e.g. only a short glances should be required to spot important information.
- Information detail about the system, e.g. the system should have adequate instruction for the driver.
- System behavior principles, e.g. TV should be automatically be restricted while the vehicle is in motion it means no images or video should be permitted.
- Overall design principles, e.g. the system must be appropriate for the use while driving and interactions must be interruptible so that the driver is able to continue his task after returning his attention back to the interaction with the system.

Additionally, some guidelines provide detailed recommendations for navigation systems, for messaging, and for using an interactive information services like internet searching [AAM 2006]. UMTRI-Guidelines also include vehicle observing guidelines and recommendations for in vehicle safety advisory, alert and warning systems [Green 1993]. In addition the overall guidelines for information and communication systems, there are some more precise guidelines available. The “Design guidelines for safety of the in-vehicle information systems” from Stevens [Stevens 2001] deals entirely with recommendations for information systems that provide the driver with information to his journey, such as navigation, accident warnings or congestion. Besides recommendations for traffic and road information systems, Ross [Ross 1996] make recommendations for collision avoidance und autonomous intelligent cruise control, as well as for road infrastructure systems. There are some explicit guidelines for crash prevention warning devices [Lerner 1996] that comprise among other things crash warning devices, blind spot warning devices and driver state monitoring devices. Campbell [Campbell 1998] provided guidelines for advanced traveler information systems and commercial vehicle operations. SAE in [SAE 2004; SAE 2002] recommended practices for evaluating the ease of access of navigation systems and route guidance functions while driving. A further method for evaluating a system regarding specific criteria is checklists [Stevens 1999; Kopf 1999; Brook-Carter 2002]. The checklist is designed for use during the early stages of the system development process and functional specification of driver assistant systems. ADAS Quick Check [Brook-Carter 2002] takes the "European Statement of Principles on Human Machine Interface for In-Vehicle

Information and Communication Systems" [European Communities 2007] into account and supports the development process in all phases of the product lifecycle: system concept, virtual prototypes, and physical prototypes, product on the market and generic products. Most of the presented guidelines comprise and refer to international standards that provide essential aspects for interaction design in cars. ISO 3958 deals with driver's operating distances and describes hand-reach envelopes for passenger cars [ISO 1996]. The data are appropriate for the left-hand drive vehicles, as well as for the right-hand drive vehicle. Another moderately general aspect can be found in ISO 2575 [ISO 2575:2010] about the uniformity of symbols for the controls, indicators and tell-tales to ensure identification and enable use of these devices. Also. Other standards deal with ergonomic design aspects of transport information and control systems (TICS) with respect to visual, auditory and dialogue aspects. ISO 15008 [ISO 2009] defines ergonomic specifications for displays, such as image quality, legibility of characters and color recognition, that contain dynamic visual information. The document also provides recommendations as to which color combinations are beneficial and how to deal with intermittent and image stability. ISO 15006 provides ergonomic specifications for the design and installation of auditory displays that present speech and tonal information while driving [ISO 2004]. It deals with signal specifications, information coding and safety-relevant messages. ISO 15005 describes principles for the design process of TICS's dialogue management [ISO 2002]. Its goal is to moderate driver workload and safeguard effective and efficient use of TICS.

Issued by the Department's National Highway Traffic Safety Administration (NHTSA) in 2012, the voluntary guidelines establish explicit recommended principles for electronic devices installed in vehicles at the time they are manufactured that require drivers to take their hands off the wheel or eyes of the road to use them. The guidelines comprise recommendations to bound the time a driver must take his eyes off the road to perform any single interaction to two seconds at a time and twelve seconds in a total to complete a task. The guidelines also recommend restricting several operations unless the vehicle is stationary and in park, such as:

- Manual text entry for the purposes of text messaging and internet browsing;
- Video-based entertainment and communications, such as video phoning or video conferencing;
- Display of certain types of text with a lot of information, including text messages, web pages, social media content.

The recommendations charted in the guidelines are consistent with the results of a new NHTSA naturalistic driving study [NHTSA 2013]. The study revealed that visual-manual tasks associated with hand-held phones and other portable devices increased the risk of getting into a crash by three times. Thus, with smart cars, there’s a modification in the user expectations as well as the way of interaction delivered in the car. There’s necessity to make this guide lines more human-centered rather than just functional or visual appeal of the design considering the driver distraction and the ease of use in center.

CHAPTER 3

3. IN-CAR VOICE INTERACTION (IVI) STATE OF THE ART

This chapter introduces voice recognition, types of voice recognition systems, its widespread usage, examples of current in-car voice interfaces, supporting technologies in the automotive industry and limitations. It also discusses the serious problems regarding increased driver distraction and cognitive load due to faulty in-car voice interaction systems.

3.1 Voice Recognition (VR) Technology Road-map

What is Voice Recognition? It is the process of converting spoken input to text. VR is sometimes referred to as speech-to-text. VR is also referred to as Speech Recognition (SR), which is the software technology that lets the user control computer functions and dictate text by voice. For example, a person can move the mouse cursor with a voice command, such as “mouse up”; control application functions, such as opening a file menu; create documents, such as letters, reports or start a media player by saying “Music”.

In 1950s voice recognition system was supposedly a dream. The first VR systems were talented of only understanding digits. Bell Laboratories designed the "Audrey" system in 1952, which accepted only digits spoken by a single voice command. Ten years later, IBM revealed its "Shoebox" machine at 1962 World's Fair, which could comprehend 16 words pronounced in English. Laboratories in the United States, Japan, England, and the Soviet Union industrialized hardware dedicated to recognizing spoken sounds, growing VR technology to support four vowels and nine consonants. Then VR technology made major advances in the 1970s, Carnegie Mellon University established "Harpy" speech-understanding system. Harpy could recognize 1011 words, around the vocabulary of an average three-year-old.

Over the next decade in 1980s, VR vocabulary soared from about a few hundred words to several thousand words, and had the potential to distinguish an unlimited number of words. This was accomplished with the use of a statistical method known as the *Hidden Markov Model*. Rather than just using templates for words and observing for sound patterns, HMM considered the probability of unknown sounds' being words. In the '90s, computers with faster processors finally arrived and VR software became viable for ordinary people. In 1990, Dragon launched the first consumer VR product, Dragon Dictate, for an incredible price of $9000. Seven years later, Dragon launched an improved VR product, Dragon NaturallySpeaking. The application recognized continuous speech, so we could speak naturally, at about 100 words per minute. However, we had to train the program for 45 minutes, and it was still expensive at $695 and sometimes faulty even in controlled environments. In 2000s Mac OSX and Windows Vista were first operating systems to have inbuilt voice recognition application. Windows VR and OS X's voice commands were interesting, but not as accurate or as easy to use as a plain old keyboard and mouse. By the year 2001, computer voice recognition had topped out at 80 percent accuracy. But near the end of the decade, the technology's development seemed to be stalled. Recognition systems did well when the language universe was limited--but they were still "guessing," with the assistance of statistical models, among similar-sounding words, and the known language universe continued to grow as the Internet grew.

The voice recognition technology progress began to edge back into the forefront with Google Voice Search app for the iPhone, improved version of dragon NaturallySpeaking, Apple's Siri, Windows' Cortana and many other VR systems. The impact of Google's app is significant for two reasons. First, cell phones and other mobile devices are ideal vehicles for VR, as the desire to replace their tiny on-screen keyboards serves as an incentive to develop better, alternative input methods. Second, Google had the capacity to offload the processing for its app to its cloud data centers, connecting all that computing power to perform the large-scale data analysis necessary to make matches between the user's words and the enormous number of human-speech examples it gathered. In short, the bottleneck with Voice Recognition has always been the accessibility of data, and the ability to process it efficiently. Google's app adds to its analysis, the data from billions of search queries, to better predict what we're probably saying. In 2010, Google added "personalized recognition" to Voice Search on the Android phones, so that the software could record users' voice searches and produce a more accurate speech model. The company also added Voice Search to its Chrome browser in mid-2011. Remember how we started with 10 to 100 words, and then graduated to a few thousand? Google's English Voice Search system now incorporates 230 billion words from actual user queries.

In mid-2011, Apple had launched Siri, a personal assistant that takes voice commands. Like Google's Voice Search, Siri relies on the cloud-based processing. It draws what it knows about us to generate a contextual reply, and it responds to our voice input with personality. Voice recognition has gone from utility to entertainment. The number of applications of voice recognition has improved and comprises voice dialing (e.g. "Call office"), call routing (e.g. "I would like to make a collect call"), home automation (e.g. find a podcast where particular words were spoken), simple data entry (e.g., entering a phone number), speech-to-text processing (e.g. dictation), customer service applications, etc. These apps not only let us control our PC by voice or convert voice to text but they also support multiple languages, offer assorted speaker voices for us to choose from, and integrate with our mobile devices.

Looking back on the development of VR technology is like watching a child grow up, progressing from the baby-talk level of recognizing single syllables, to building a vocabulary of the thousands of words, to answering questions with quick and witty replies, as Apple's so called super smart virtual assistant Siri does. The Gartner Hype Cycle for Emerging Technologies, 2014 showed interesting results which is further discussed in detail.

About Gartner:

Gartner, Inc. (NYSE: IT) is the world's leading information technology research and advisory company. The company delivers the technology-related insight necessary for its clients to make the right decisions, every day. From CIOs and senior IT leaders in corporations and government agencies, to business leaders in high-tech and telecom enterprises and professional services firms, to technology investors, Gartner is the valuable partner to clients in approximately 10,000 distinct enterprises worldwide.

About Hype Cycle:

First, a quick refresher on the Hype Cycle itself. Introduced in 1995, the Hype Cycle (which is not, in fact, a cycle as such) is an idealized model of a typical technology's progress from a Technology Trigger (TT), through a period of increasing visibility to a Peak of Inflated Expectations (PoIE), where negative coverage based on the first-generation products precipitates a slide into the Trough of Disillusionment (ToD). This is followed by a slower recovery, on the back of second-generation and subsequent products, up the Slope of Enlightenment (SoE) to the Plateau of Productivity (PoP), where at least 30 percent of the technology's target audience has adopted it (or is planning to):

Since last few years, most of the new cars come with inbuilt voice recognition system. The Gartner Hype Cycle for Emerging Technologies, 2014 is shown in fig 3.1. The hype cycle indicates that the VR technology is about to reach the Plateau of Productivity (PoP) in less than two years. Figure 3.1 is clear indication of how VR (SR) has become a mature technology and it’s not a dream anymore.

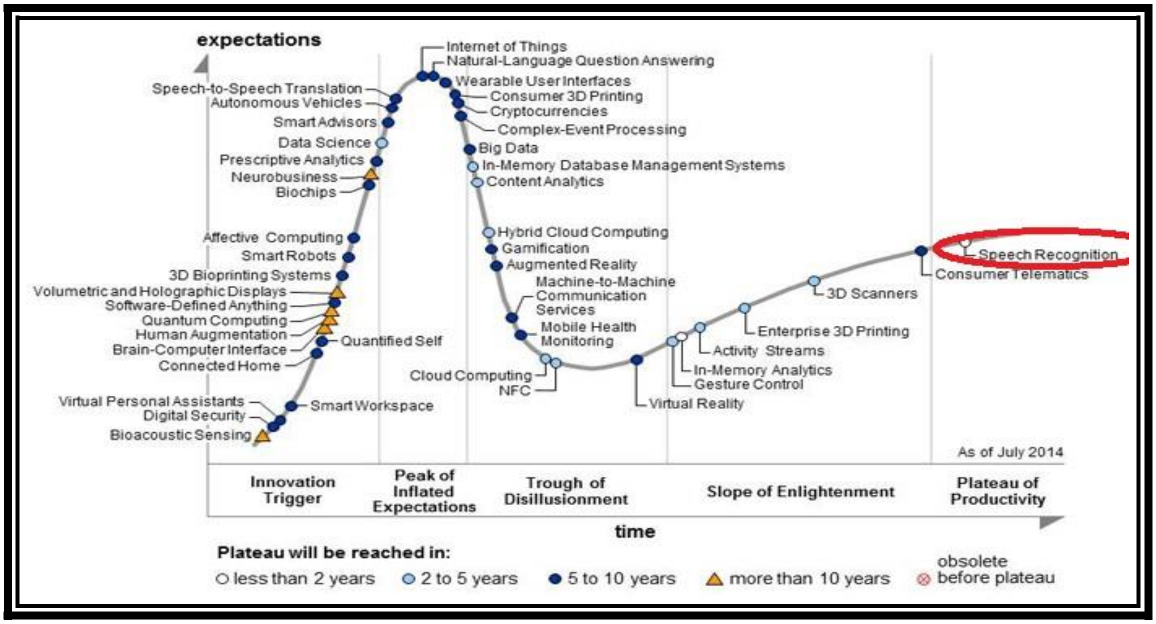


Figure 3.1: The Gartner Hype Cycle for the Emerging Technologies, Gartner-2014

There are two kind of VR systems used in wide variety of applications. The systems that use training are called "speaker-dependent" VR systems and the systems that do not use training are called "speaker-independent" VR systems.

3.1.1 Speaker Dependent Voice Recognition

Speaker-dependent software works by learning the unique characteristics of a single person's voice, in a way similar to voice recognition. New users must first "train" the software by speaking to it. These systems analyze the person's specific voice and use it to fine-tune the recognition of that person's speech, resulting in more accurate transcription. This often means users have to read a few pages of text to the computer before they can use the VR software.

3.1.2 Speaker Independent Voice Recognition

Speaker-independent software is designed to recognize anyone's voice, so no training is involved. This means it is the only real option for applications, such as interactive voice response systems where businesses can't ask callers to read pages of text before using the system. The downside is that speaker-independent software is generally less accurate than speaker-dependent software. Voice Recognition engines that are speaker independent generally deal with this fact by limiting the grammars they use. By using a smaller list of recognized words, the speech engine is more likely to correctly recognize what a speaker said.

3.2 Voice Recognition Becomes Main Stream in the Cars

In this section, we discuss the strengths of voice interaction as individual modality, and how it has become widespread in the cars. Among other things, speech input offers speed, high-bandwidth information, and the relative ease of use. It also permits the user's hands and eyes to be busy with a task, which is particularly valuable when users are in motion or in natural field settings. Users tend to prefer speech for functions like describing objects and events, sets and subsets of objects, out-of-view objects, conjoined information, past and future temporal states, as well as for issuing commands for actions or iterative actions.

The auto consumers crave connectivity, whether it's using messaging, navigation or social media, listening to music or accessing the seemingly endless amount of content on the mobile Web. Also, people want to be connected all the time – even behind the wheel. Automakers are working hard to balance the demands of their consumers and bring connectivity and content into the car without bringing in added distractions. There comes a need to enable drivers with a safer, smarter way to engage those systems – otherwise drivers cannot take full advantage of what's possible for today's smart cars. Regulators have called for bans on using hand-held devices behind the wheel because of concerns regarding distracted driving. So most car makers have started to adopt voice recognition systems as a must feature in the car.

Speech interaction in-car has become a key feature because visual-manual alternatives are distracting, causing drivers to look away from the road, and increasing the risk of crashing. Stutts [Stutts 2001] reported that adjusting and controlling entertainment systems and climate-control systems and using cell phones accounted for 19% of all the crashes related to distraction. The fact that the use of the entertainment systems is ranked second among major causes of these crashes supports the argument that speech interfaces should be used for the music selection. Tsimhoni [T. Simhoni 2008] reported that 82% less time was needed for drivers to enter an address using a speech interface as opposed to using a keyboard, indicating that a speech interface is preferred for that task. Given these advantages, suppliers and auto manufacturers have put significant effort into developing speech interfaces for the cars and they still have a long way to go.

People want to be connected in their car just as they are in their home or wherever they may be. Automakers do not want to give up on a feature their customers want, especially if it is offered by their competitors. The voice recognition feature inside the car has become an important selling point for automakers. It's already hard to find a new luxury vehicle that does not have the technology, and AAA foundation predicts that in the next five years, there would be a five-fold jump in the new cars having inbuilt voice recognition system. It seems that in the next five years there will hardly be any new car coming without a voice recognition feature. Also, a total share of the car with voice recognition is expected to reach 50% or more by 2020. A survey by Statista is displayed in figure 3.2, which shows the proportion of the cars with a voice recognition system installed in 2012 and 2019 [Statista 2015b]. The share of the cars equipped with a voice recognition system is predicted to be increased from 37 percent in 2012 to 55 percent in 2019.

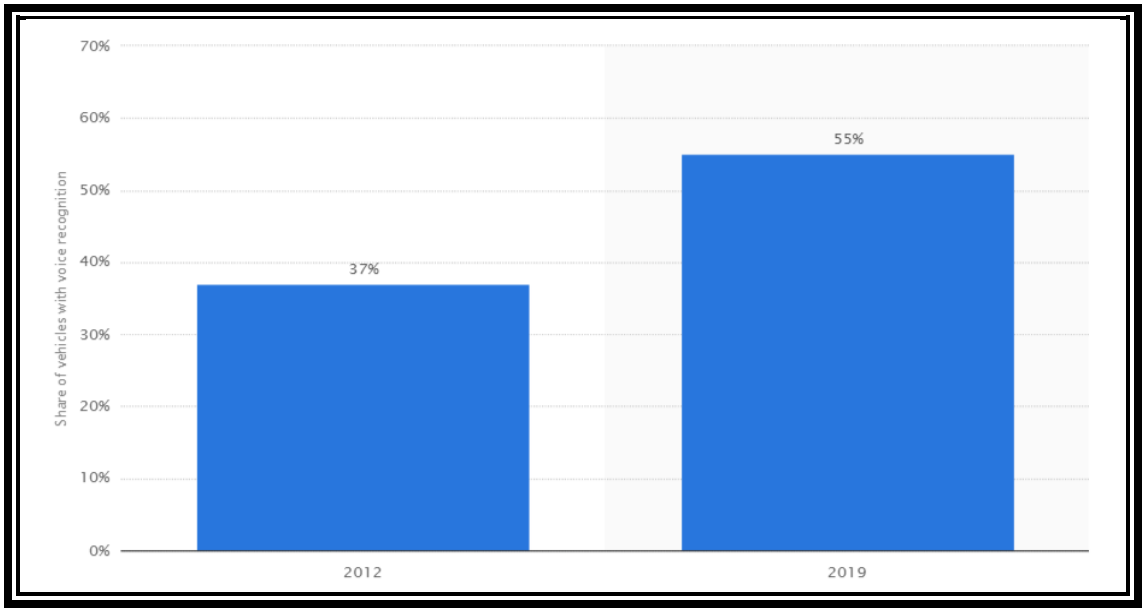


Figure 3.2: New Cars with a Voice Recognition System in 2012 and 2019

The survey also shows that the global revenue from voice recognition units in the vehicles is projected to grow to about 170 million U.S. dollars in 2019. The figure 3.3 displays the global revenue from the installation of a voice recognition in cars in 2011 and 2019 [Statista 2015a].

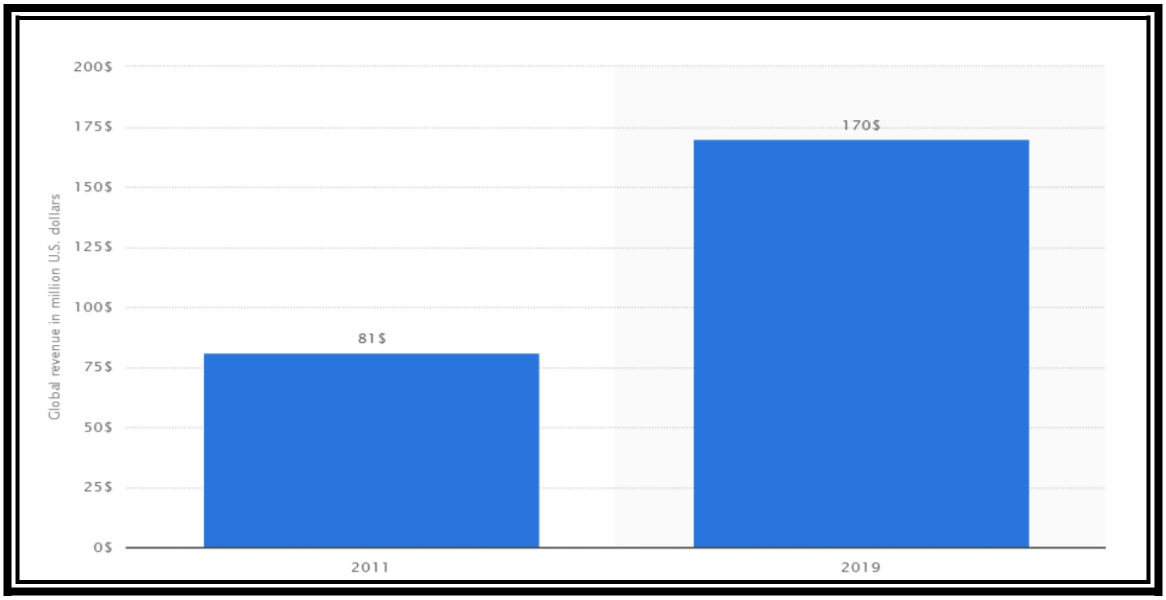


Figure 3.3: Global Revenue from Installed VR in the Cars in 2011 and 2019

3.3 Current Examples of the In-car Voice Interaction Systems

It is appropriate to ask what is known about the design and evaluation of voice interaction for the cars and how they can be improved. To have more idea about the domain, we will see some examples of the current automotive speech interfaces. In the USA, current voice interfaces include Ford SYNC, Chrysler UConnect, GM MyLink, Hyundai Genesis, and Toyota navigation with Entune. The commonly supported applications are navigation (e.g., destination entry, route guidance, and traffic information) and music selection (selecting, playing, and pausing songs on MP3players, AM/ FM/XM radios), as well as those related to cellular phones (answering and placing calls, searching contact lists, and various tasks associated with text messages). Some of the examples are as follows:

- The CHAT system uses an event-based, message-oriented system for the architecture with core modules of Natural Language Understanding (NLU), Dialogue Manager (DM), Content Optimization (CO), Knowledge Management (KM), and Natural Language Generation (NLG). CHAT uses the Nuance 8.5 Voice Recognition engine with class-based dynamic grammars, and Nuance Vocalizers'

Text-to-Speech engine. There are three main applications— navigation, MP3 music player, and restaurant finder—to represent important applications in a vehicle.

- CU-Move system is an in-vehicle, naturally spoken dialogue system, which can get real-time navigation and route planning information. The dialogue system is based on the MIT Galaxy-II Hub architecture with base components from CU-Communication system, which is mixed initiative and event driven. This system automatically retrieves the driving direction through internet with route provider. The dialogue system uses the CMU Sphinx–II speech recognizer for Voice Recognition and Phoenix Parser for semantic parsing.
- Linguatronic is a speech-based command and control system for telephone, navigation, radio, tape, CD, and other applications. The recognizer used in this device was speaker independent. SENECASLDS consists of five units: COMMAND head unit connected via an optical Domestic Digital Bus to the Global System for Mobile Communication module, the CD Changer, and Digital Signal Processing module. The system is a command-based speech control of entertainment (radio and CD), navigation, and cellular phones. The Voice Recognition technology of SENECASLDS is based on the standard Linguatronic system using the following methods to match the user speech: spell matcher, Java Speech Grammar Format, voice enrollments (user-trained words), and text enrolments. For the dialogue processing, the SENECASLDS uses a menu-based Command & Control dialogue strategy, including top-down access for main function and side access for sub function.
- Out of these systems, probably SYNC has received most of the attention. SYNC is a fully integrated, voice-activated in-vehicle communication and entertainment system [10] for Ford, Lincoln, and Mercury vehicles in North America. Using

commands in multiple languages, such as English, French or Spanish, drivers can operate navigation, portable digital music players, and Bluetooth-enabled mobile phones.

- VICO was a research project that concerned a natural language dialogue prototype. As the interface did not exist, researchers used the Wizard of Oz method to collect the human-computer interaction data. Here, a human operator, the wizard, was simulated system components—Voice Recognition, natural language understanding, dialogue modeling, and response generation. The goal of this project was to develop a natural language interface allowing drivers to get time, travel (navigation, tourist attraction, and hotel reservation), car, and traffic information safely while driving.
- Volkswagen also developed its own in-vehicle speech system. Detailed information about the architecture and methods used to design the system are not available. Supported applications include navigation and cellular phones.
- The best-known non-automotive natural speech interface is Siri, released by Apple in October 2011. Siri can help users make a phone call, find a business and get directions, schedule reminders and meetings, search the web, and perform other tasks supported by built-in apps on the Apple iPhone4S and iPhone5.
- Similarly, Google's Voice Actions supports voice search on the Android phones. This application supports sending text messages and email, writing notes, calling businesses and contacts, listening to music, getting directions, viewing a map, viewing websites, and searching webpages. Both Siri and Voice Actions require off-board processing, which is not the case for most in-vehicle speech interfaces.

3.4 IVI a Solution and a Cause of Driver Distraction

As we have seen in this section, voice recognition is believed to be the solution to physical distraction, the same is perceived by the some of the state governments. The use of handsets while driving is illegal in 14 states, whereas the use of "hands-free" voice controls is generally encouraged. Most of the people hold a common perception that voice recognition technology is safer because the driver can use it while holding the steering wheel and looking at the road. In contrast, the study by AAA foundation in April 2013 showed that the mental workload from performing complicated tasks slows reaction times, whatever the driver is doing with his or her hands. Figure 3.4 shows the study results. It indicates that composing email or text messages using voice command is highest level of cognitive distraction [AAA 2013: Strayer 20013a]

Figure 3.4: Research Results by AAA Foundation 2013

Moreover, other research shows using a speech interface still requires cognitive demand, which can interfere with the primary driving task. For example, Lee [Lee 2014] showed that drivers' reaction time increased by 180ms when using a complex speech-controlled email system (three level soft menus with four-to-seven options for each menu) in comparison with a simpler alternative (three levels of menus with two options per menu). With three out of four drivers believing that hands-free technology is safe to use, people may be surprised to learn that these popular new vehicle features may actually increase mental distraction, according to research by the AAA Foundation for Traffic Safety in 2013. This research can serve as guidance to manufacturers who market hands-free systems as safety features. The studies involved 162 University of Utah students and other volunteers who performed a series of tasks (such as calling, texting, tuning the radio) using various voice-based, interactive technologies while they looked at a computer screen, operated a driving simulator and drove real cars on a loop through Salt Lake City's Avenues district. In the real cars, drivers were accompanied by at least one researcher responsible for data collection and for safety spotting to prevent them from mishap such as running stop signs. Video cameras recorded their actions and the road ahead. The study established a five-point scale for measuring driver distractions: 1 is the least distractive, which represents the mental workload of driving without distraction, while 5 represents severe distraction caused when drivers performed a complex math-and-memorization test. The study was done with two different purposes and both of them used the same scale. The first study scored common voice interactions systems with specific infotainment systems in some of the most common auto brands on U.S. roads. The study results are shows in Table 3.1, from least distracting to most distracting:

Table 3.1: In-Car Voice Interaction System and Cognitive Distraction.

In-car Voice Interaction system	Cognitive distraction (1-5, 1 being least distraction)
Toyota's Entune System	1.7

Hyundai's Blue Link System	2.2
Chrysler's Uconnect System	2.7
Ford's SYN with Ford My touch System	3.0
Mercedes's COMMAND System	3.1
Chevrolet's MyLink System	3.7

The second study rated distractions from eight different ways of interacting with a car by voice command. Table 3.2 shows the results from the study with the same scale, 1 being least distractive and 5 being the most distractive.

Table 3.2: Cognitive Distraction by Task Specific Voice Commands

Specific task completion using Voice commands	Cognitive distraction (1 = least distraction)
To use single simple voice commands, like turn on heat or tune the radio	1.88
To ask a natural, recorded voice to play emails and texts	2.04
To ask a computerized voice to play emails and texts	2.31
To use an error-free, voice menu system to navigate to destinations	2.86
To ask a computerized voice to play and compose emails and texts	3.06
To ask a natural, recorded voice to play and compose emails and texts	3.09
To use an error-prone voice-based menu system to navigate to destinations	3.67

To use Apple's Siri (iOS 7) to navigate, send and receive texts, make Facebook and Twitter updates	4.14

Figure 3.5 below shows the visual ratings for all of the different task as seen above categorized by the way of interaction using the voice commands while operating the systems from least to most distracting. Here also, 1 being the least distraction and 5 being the most distractive.

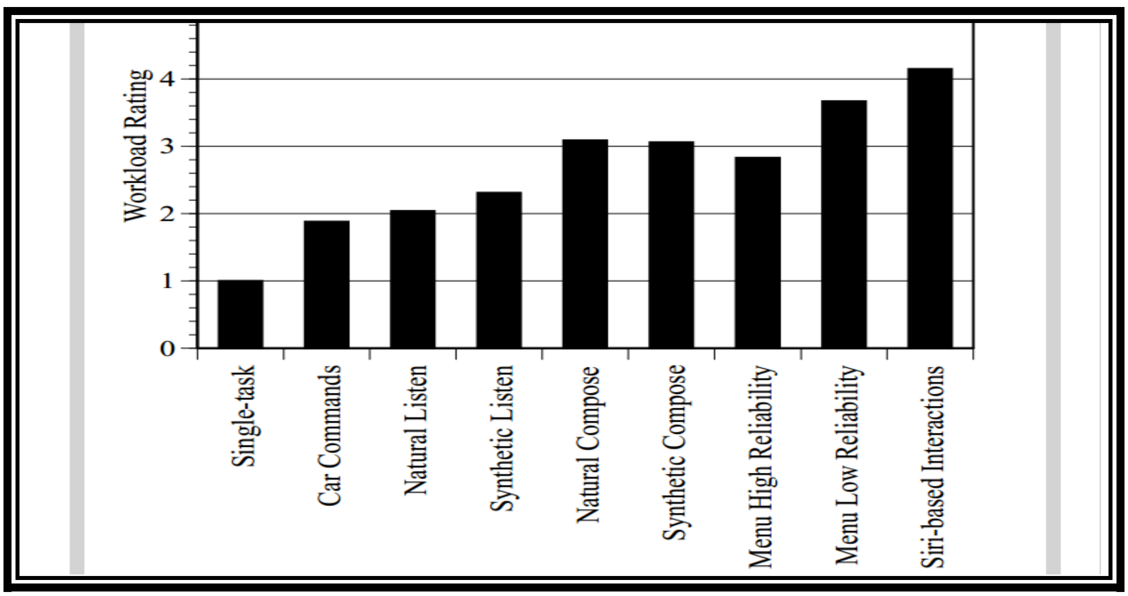


Figure 3.5: Task Specific Cognitive Load Ratings

The above research shows that some of the most advanced technology, such as Siri, can lead to high levels of distraction while driving. When these systems become more complex, like sending text messages or posting to Facebook, it pushes the workloads to pretty high levels and may be dangerous while driving. The research revealed that the voice-based systems were more distractive because they were too complex, mentally demanding, difficult to use and often inaccurate at recognizing voice commands. "It's time to consider limiting new and potentially dangerous mental distractions built into cars," said the CEO of AAA foundation after this study, "particularly with the common public misperception that hands-free means risk-free."

A separate study by the market research firm J.D. Power & Associates found that the rate of the complaints about built-in voice recognition systems is nearly four times the rate of reported problems with transmissions or cup holders. In Figure 3.5, first part show the data about the percentage of a factory-installed voice recognition equipment by brand for 2014 models and second part is the data from J.D Power and associates which shows the number of problems reported per 100 cars. From the research it is clear that so called less distractive hands-free solutions like voice recognition (8.3) and Bluetooth (5.7) are the top most in the complaints received.

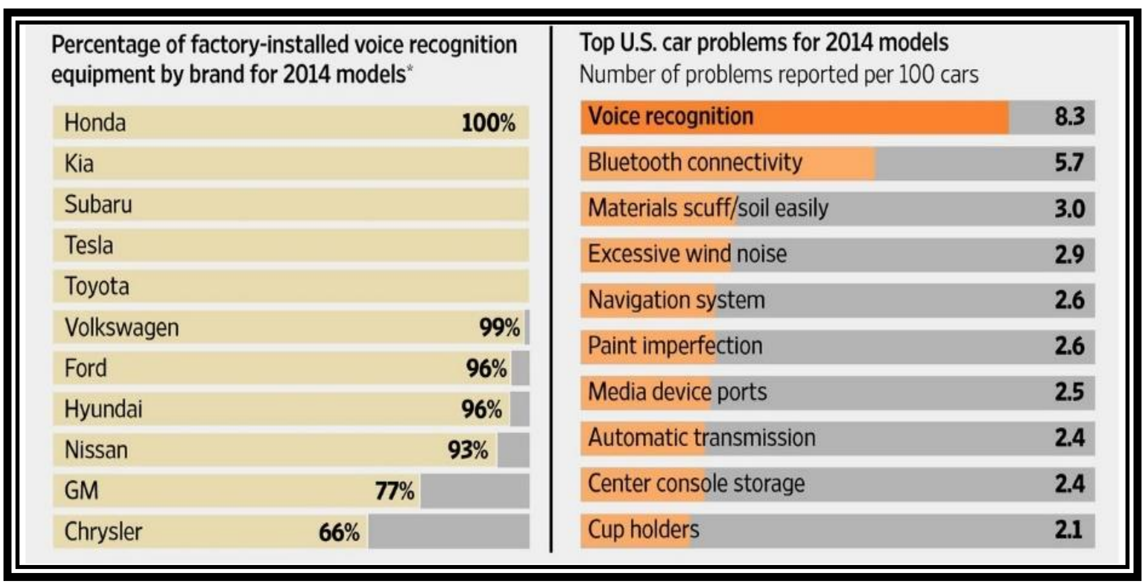


Figure 3.6: Car Models Made in the North America for U.S Market, 2014

To put all of these findings in context, the research revealed that listening to the radio rated as a category 1 distraction which means mild distraction; talking on a hand-held or hands-free cell phone resulted in a category 2 distraction which means moderate distraction; and using an error-free speech-to-text system to listen to and compose emails or texts was a category 3 distraction which is the highest level of distraction. If voice interaction is not designed carefully in the voice recognition systems, it can lead to very dangerous consequences.

3.5 IVIS: Technology Limitations

The voice-recognition technology is mature enough and works almost perfectly in an ideal environment without noise but still there are limitations regarding its use in automotive applications. The main limitations are environment noise, hardware limitations in terms of computing power, and cognitive distraction due to certain kind of voice interactions. This section presents challenges in in-car voice interaction systems.

Accuracy:

- Error rates increase as the vocabulary size grows.
- Vocabulary is hard to recognize if it contains confusable words.

Speaker dependence vs. independence:

- A speaker-dependent system is intended for use by a single speaker. It works perfectly with limited vocabulary and predefined set of commands but it requires training and lots of cognitive load to remember commands.
- A speaker-independent system is intended for use by any speaker but it contains very large vocabulary and hence, less accurate and more difficult.

Isolated, Discontinuous or continuous speech:

- With isolated speech single words are used, therefore it becomes easier to recognize the speech. Isolated word recognizers usually require each utterance to have quiet (lack of an audio signal) on both sides of the sample window. It doesn't mean that it accepts single words, but does require a single utterance at a time.

- With discontinuous speech full sentences separated by silence are used, therefore it becomes easier to recognize the speech but because of the challenges regarding environment noise in-car it is more prone to errors.
- With continuous speech, naturally spoken sentences are used, therefore it becomes harder to recognize the speech, different from both isolated and discontinuous speech.

Task and language constraints:

- Read vs. Spontaneous Speech: When a person reads it's usually in a context that has been previously prepared, but when a person uses spontaneous speech, it is difficult to recognize the speech because of the dis-fluencies (like "uh" and "um", false starts, incomplete sentences, stuttering, coughing, and laughter) and limited vocabulary.
- Adverse conditions, such as child crying in back seat, FM or AM playing, engine noise, etc.

Speed and delayed response**:**

- To have large vocabulary and highly sophisticated Voice Recognition engine it requires high processing CPU.
- Background noise in-car environment also affect system performance in terms of processing speed.

CHAPTER 4

4. INNOVATION PROCESS FOLLOWED TO DESIGN THE HCaI

This chapter is about the critical analysis of state of the art in the automotive industry as a whole, what is specific to muscle cars and where we are heading in terms of features, technology, and in-car interaction design. We followed our innovation process to design the interactive HCaI. It started with 360 degree analysis (360): this includes the research exploring the current in-car technologies, such as in-car voice recognition [is analyzed and discussed in chapter 3 in detail (pg.42-59)] and ADAS [is analyzed and discussed in chapter 6(pg.118-135)]. It also includes searching, collecting and analyzing about 400 photographs of the car cockpits from the different car models and the different car categories like economy, premium, muscle, sports, and luxury. After having holistic view of automotive domain, we moved to General domain (G) analysis (competitor's analysis): it is the same as the 360 degree analysis but for only the technology competitors of Chevrolet Camaro in the automotive market throughout the world.

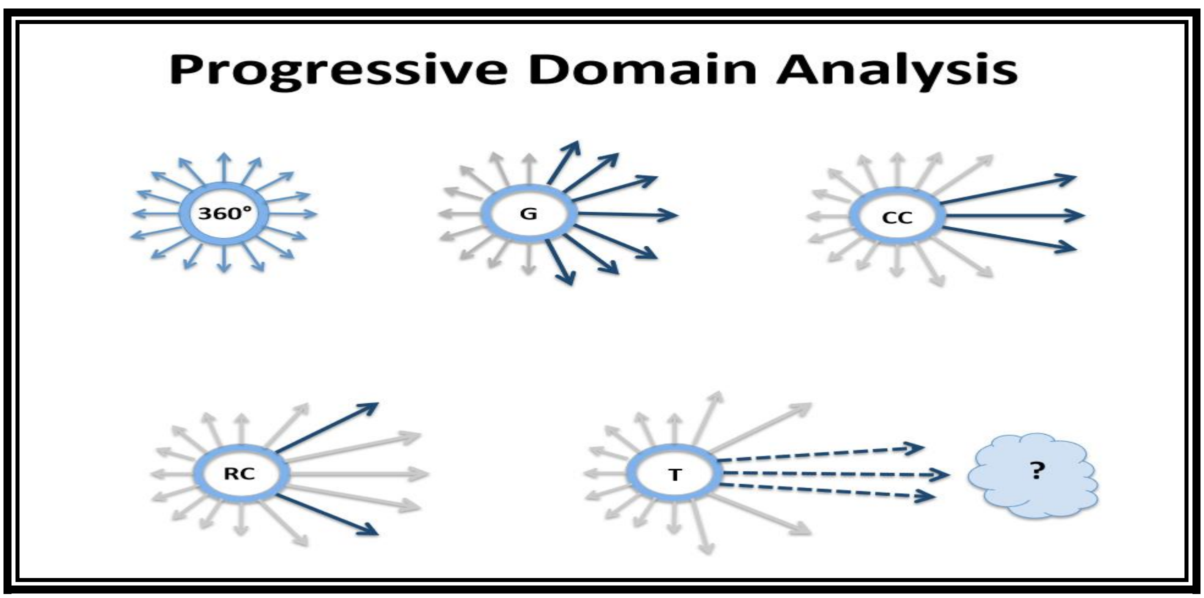


Figure 4.1: Progressive Domain Analysis

Third, close competitor's (CC) analysis: it includes the close competitors of Chevrolet Camaro in the muscle car category to get an idea of what's the similarity and differences in the designs of muscle cars in the North American market. Fourth, remote competitor's (RC) analysis: includes the analysis of the remote market competitors of Chevrolet Camaro in the muscle car category. Fifth, future trends (T) analysis: Looked into the future concept cars to identify the trends and get the idea of what kind of innovations are going in the automotive domain. Figure 5.1 shows the visual flow of the progressive domain analysis followed as the innovation process for the work.

In a typical interaction design fashion, the analysis of the past and the present HMI is given by looking at following terms:

- Controls: tools or devices which offer control of the in-car functions (e.g. a knob on a music player).
- Affordance: the nature of manipulation a control offers, while performing an action (e.g. a knob can be turned about on an axis).
- Mapping: developing a 'feel' for controls—the ability to understand what a control does and where it is located (an accomplished guitarist can play the instrument blind, by 'feel' or muscle memory).
- Learnability: the ability to understand the way a control behaves over time (e.g. turn the knob anti-clockwise to decrease volume).
- Modes: the number of ways a tool or a device can be used and accessed by switching to a new function (e.g. the same knob can also be used to control brightness).
- Distractions: the design flows causing or adding more diversion from natural interaction.

4.1 General Domain Analysis: - 360 Degree Review

The 360 degree review is about knowing the automotive domain for the HCaI and analyzing the features, technology and interaction design of most of the car categories, such as Economy cars, Premium cars, Sports cars and Luxury cars.

4.1.1 Economy Cars

This category of cars comes under minicars, compact and family cars with fuel economy and low prince. Analysis of the following cars including Kia Rio, Ford Fiesta, Ford Focus, Honda Accord, Volkswagen Polo, Toyota Carroll, and ad a mid-size car Chevrolet Malibu is given in table 4.1. As mentioned in this thesis scope (section 1.6 p.12-13), images of the concerned areas like car center console, instrument cluster, steering wheel and front dashboard of the car is taken for each of these cars. As providing extra features and functionalities ads up to the total cost, these cars don't have all the features of the high-tech smart cars. But this segment has also seen a shift from no infotainment display to a digital or touch based display in the center console. The table 4.1 shows the in-car interaction design analysis of the Economy cars.

Table 4.1: In-Car Interaction Design Analysis of the Economy Cars.

Dashboard	Center stack (CS)/infotainment	Instrument-Cluster (IC)	Steering Wheel (SW)
1. Kia Rio			
			
Analysis:- - A Touch display in the CS with so many small icons & menus -No groupings - A Lot of shortcut buttons on a SW -Too much info on the IC including numbers			

2. **Ford Focus**			
			
Analysis:- -Nice grouping & big buttons in the CS -But fo- display is very small, deep and higher -IC with analog gauges and small digital display			
3. **Ford Fiesta**			
			
Analysis:- -Info-display very deep and higher -Very small buttons even hard to feel without looking at - A Lack of groupings -IC with analog gauges and small digital display -only useful shortcut buttons on the SW			

4. Toyota Corolla

Analysis:-

- A Touch display in the CS with too much info and too many small icons and menus.

-A Lack of grouping & Scattered design

-Good, less crowded IC and SW designs

5. Honda Accord

Analysis:-

-Two displays in CS one for the media and one for the navigation

-Secondary display is too high and deep

-Nice groupings but no direct mapping of controls

-Crowded IC with multi-purpose gauge

-Limited shortcuts on the SW

6. Volkswagen Polo




Analysis:-

-Touch display with too much info and small icons.

-Too many small button just for the radio controls.

-Nice grouping of climate controls with info-display

-Analog IC with small digital display

-Clear SW design

7. Nissan Versa




Analysis:-

-Touch display in CS with too much info

-Nice grouping of controls in the CS

-Analog IC with small digital display

-Only useful shortcut on the SW

<table>
<tr><th colspan="4">8. Chevrolet Malibu</th></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Analysis:-
-Nice grouping but too many redundant small buttons
-Touch display with My link
-Analog cluster with small digital display contain numbers & system status icons
-only useful shortcut buttons on the SW</td></tr>
</table>

4.1.2 Premium Cars

This category of the cars comes under the compact, mid-large, and large-family cars with. This class of the cars is very much influenced by technology and it comes overloaded with a lot of features and functionalities. The consumer is ready to pay for the extra feature like ADAS, voice recognition, and fancy instrument cluster or infotainment. So automakers are ready to do more for this segment and outsourcing of the infotainments and ADAS loaded with features has become common. Table 4.2 is about the analysis of the in-car interaction design of the premium cars. This category includes the cars, such as Ford Taurus, Toyota Avalon, Acura TLX, Audi A4, BMW 3 series, Cadillac CST, Volvo S80, Chrysler 300, and Chevrolet Impala. These are the main competitors in the market for the premium category. Most of them are following the same trend of adding an extra small digital display on the instrument cluster to reduce the distraction. The small display is basically showing the navigation media or climate control status updates.

Table 4.2: In-Car Interaction Design Analysis of the Premium Cars.

Dashboard	Center stack (CS)/infotainment	Instrument-Cluster (IC)	Steering Wheel (SW)
1. Ford Taurus			
			
Analysis:- -Touch display contained climate, navigation, phone & media controls shortcut on the screen -Screen provide too much info at a time with small icons & menus -So many shortcut buttons on the SW -IC with gauges & digital display on the left side with small number text			
2. Toyota Avalon			
			
Analysis:- -A Touch display in the CS with 2 manual control knobs and 10 small buttons besides.			

<table>
<tr><td colspan="4">-Small secondary display for the climate controls with nice grouping but very small buttons
-IC with gauges and small digital display containing too much info</td></tr>
<tr><td colspan="4">3. Acura TLX</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Analysis:-
- A CS full of many small buttons
-Lack of grouping and in-proper user space with a cluttered design
-Deep & small Info-display
- A SW full of many shortcut buttons</td></tr>
<tr><td colspan="4">4. Audi A4</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Analysis:-
-A Touch display in the CS inclined towards driver but contained too much info
-Vertical center stack less crowded but still small buttons</td></tr>
</table>

-Media controls moved to horizontal CS

-Nice groupings

-Good, less crowded IC and SW designs

5. BMW3 series

Analysis:-

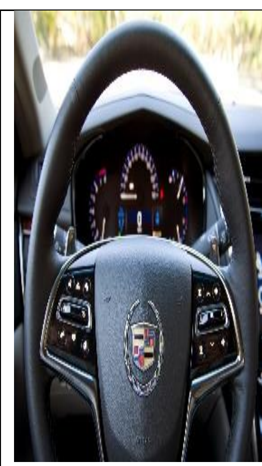
-Two tablet alike displays one 8 inch touch display in CS & the other 6 inch display as IC

- So many buttons just for the Radio controls on the CS

-IC contained too much info with numbers and replaced traditional gauges

-So many shortcuts on the SW to control both the display

6. Cadillac CTS



Analysis:-

- A Cluttered CS with no separation of buttons

-Very small thin buttons with small text description

- An IC with small digital display

-Many shortcutson the steering to control both the display

-Most widely criticized design of 2013

7. Volvo S80

Analysis:-

-Touch display at proper height

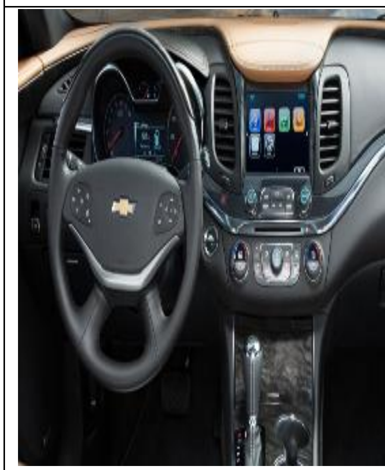
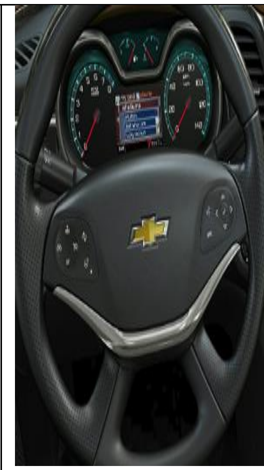
-Nice grouping of controls

-Multi-purpose gauge cluster

-Limited shortcuts on the steering

-overall dash board less crowded

8. Chrysler 300

<table>
<tr><td colspan="4">Analysis:-
-A Touch display replacing most of the manual buttons except climate controls
-Virtual cockpit in the IC with small digital display in the center
-Too many shortcut button SW to control both displays</td></tr>
<tr><td colspan="4">9. Chevrolet Impala</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Analysis:-
-Touch display with big icons and less crowded menu
-Nice grouping with separate media and climate controls
-Small buttons and improper use of space in the CS
- An IC contained gauges with small digital display
-Shortcuts on the SW to control both displays</td></tr>
</table>

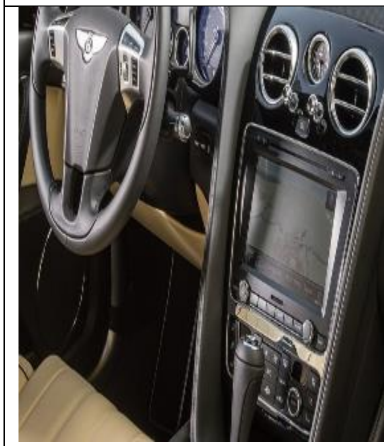
4.1.3 Sports Cars

The cars in the size of the mid-large-sports and the large-sports come under this category. This category of cars are mostly designed for the performance and aesthetic is not given as much importance as performance. So this segment has been less influenced by all the fancy and crowded center consoles. Info-display or digital touch displays in the center console are at lover height and very reach of the driver in most of the cars as these cars are slick in the design. These cars have sporty looks for the most of the parts like steering wheel, center stack, infotainment display, buttons, and instrument cluster. Table 4.3 shows the analysis of the in-car interaction design of the sports cars.

Table 4.3: In-Car Interaction Design Analysis of Sports Cars.

Dashboard	Center stack (CS)/infotainment	Instrument-Cluster (IC)	Steering Wheel (SW)
1. Ferrari 458			
			
Analysis:- - No Touch display in the CS -Analog IC with digital display on the left side of IC -Digital display is controlled by shortcuts in the SW -Media and climate control is located in the CS			

2. Bentley

Analysis:-

-Touch display in the vertical CS with 4 manual control knobs and 10 small buttons

-Height of display is lover

-Analog cluster with small digital display in the center

3. Jaguar XF

Analysis:-

- Touch display in CS with so many small icons and menus buttons

-lack of grouping and spacing with cluttered design

- A SW with lots of shortcut buttons

-Analog cluster with small digital display in the center which displays

4. Lamborghini Aventador




Analysis:

- A Touch display in the CS at low height and the CS vertically inclined towards driver

-IC is a cluttered digital display divided in to two parts, analog like speedometer and virtual infotainment with navigation, media, Radio and climate controls

-Lack of groupings

-Less crowded SW

5. Maserati Gran –Turismo




Analysis:-

- A Touch display in the CS replaces manual buttons, cultured with lots of small icons and menus

-2 manual knobs to control display

- Separate climate controls in the CS

-Analog cluster with small digital display in the center which displays

-Overall CS less crowded with physical buttons but infotainment software is complex.

6. Bugatti Veryon




Analysis:-

-Traditional design with no digital display in CS or IC

-Nice grouping in CS but very small thin buttons with small description & improper use of space

- IC comes with traditional analog dials

-Clear SW with no shortcuts

7. Chevrolet Z06




Analysis:-

-Touch display at lower height in CS

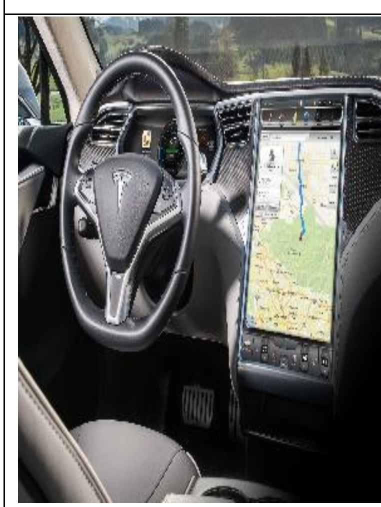
-Nice grouping and display is inclined to driver

-A single knob on the horizontal CS beside driver to control display -Analog cluster with small digital display in center which displays -Limited shortcuts on the SW

4.1.4 Luxury Cars

The high-performance cars other than sports cars comes under this segment. These are the cars most influenced in terms of style, technology and in-car interaction design. They are loaded with the latest and the greatest technology in the automotive market. Most of the innovations happen in this category of the car but in the last few years, some of the automakers have started moving into sales driven approach for this car as well just as premium cars. Apart from performance, in car technologies, such as ADAS, Heads up display, auto-park assist, voice recognition, and semi-autonomous driving features has become the center of attraction. Table 4.4 gives the detailed analysis of in-car interaction design of the luxury cars.

Table 4.4: In-Car Interaction Design Analysis of Luxury Cars.

Dashboard	Center stack (CS)/infotainment	Instrument-Cluster (IC)	Steering Wheel (SW)
1. Tesla Model S			
			

Analysis:-

-A big 18 inch touch display in the CS with full of small numbers, text, images, icons ad menus

-A display in the CS completely replaces manual knobs.

-An analog IC is replaced with digital display, lot of information and cluttered

- IC also give virtual aces to media, navigation and climate control

2. Porsche

Analysis:-

-Touch display in the vertical CS with 2 manual control knobs and 5 small buttons

-Nice grouping on the vertically inclined horizontal CS but so many buttons

-Height of display is lover

-Analog cluster with small digital display

3. Mercedes- Benz S Class

Analysis:-

-Infotainment & IC both combined in one long display with utilization of space.

-Very few buttons except Radio on the vertical CS

-The display is controlled from central controller in the horizontal CS.

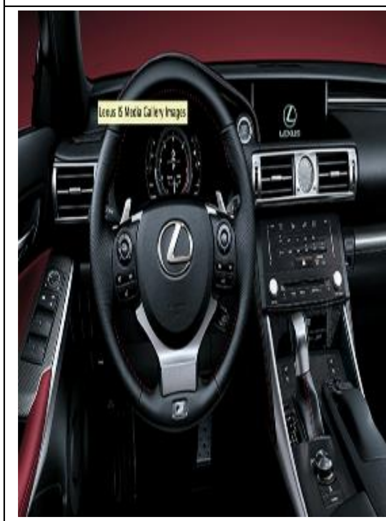
-Media control has also moved to horizontal CS.

-IC display is customized to analog like look with navigation rout visibility in the center

-A SW with lots of shortcut buttons

-Most stylish and functional design of the 2015

4. Lexus LS



Analysis:-

-A touch display in the CS at height

-The vertical CS is full of small buttons ad knobs

-Lack of groupings

-IC is a cluttered with small digital display in the center dividing analog IC

-Less crowded SW

5. BMW 7 Series




Analysis:-

-Touch display in the CS with lots of small icons and menus

-2 groups with radio and climate control on the vertical CS with so many buttons and knobs

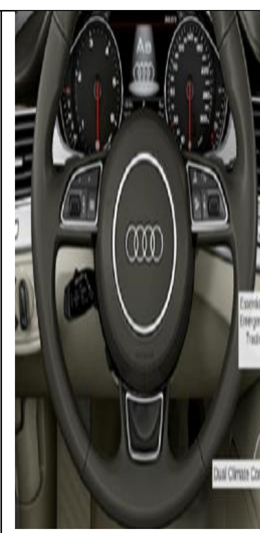
-Also, the horizontal CS is crowded with media and display controls

-Analog cluster with small digital display in the center

-Limited shortcuts on the SW

6. Audi 8



Analysis:-

-Touch display and 1 radio control on the vertical CS with so many buttons and knobs

- Climate, media, &display controls on the horizontal CS
- Nice groupings with less crowded

-Analog cluster with small digital display in center

-Limited shortcuts on the SW

7. Audi TT

Analysis:-

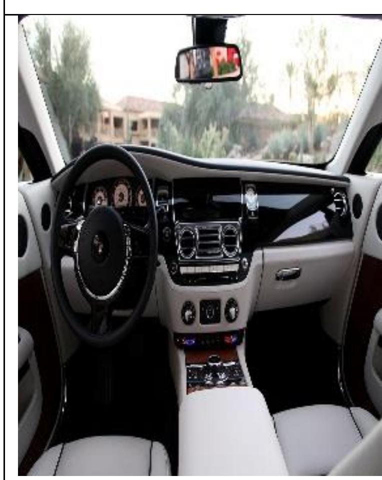
- Display from CS is moved to IC & Vertical CS has climate control group only

-Virtual cockpit Central controller and media control are on the horizontal CS beside driver

-IC display is flexible and customizable to view infotainment functionalities

-SW is crowded with shortcuts

8. Rolls Royce



Analysis:-
-Touch display and 1 radio control on the vertical CS with so many buttons and knobs
- Climate, media, &display controls on the horizontal CS
- Nice groupings with less crowded, limited shortcuts on the SW
-Analog cluster with small digital display in the center

4.2 Close Competitors Analysis

The Chevrolet Camaro comes under muscle car category. The goal of the project is to design and develop the futuristic and enhanced interaction for the muscle car. To develop competitive solution for the Camaro, close competitors analysis was essential. In United stated, the close competitors in the muscle car category are Ford Mustang and Dodge Charger. The detailed analysis of in-car environment is done for all the three muscle cars along with grouping and synthesis of the functionalities. If we look at all of three muscle cars closely, there’s not much difference in the interaction design.

4.2.1 Ford Mustang

Ford mustang is one of the famous muscle car by Ford in the North America. Also, it is one of biggest competitors of General Motor’s Chevrolet Camaro. Figure 4.2 shows the landscape of Ford Mustang 2015 and Table 4.5 shows the interaction design by main four groups.

Figure 4.2: Ford Mustang Land Scape, 2015

Table 4.5: In-Car Interaction Design Analysis of Ford Mustang.

<table>
<tr><th>Dashboard</th><th>Center stack (CS)/infotainment</th><th>Instrument-Cluster (IC)</th><th>Steering Wheel (SW)</th></tr>
<tr><td colspan="4">1. Ford Mustang</td></tr>
<tr>
<td></td>
<td>
</td>
<td>
</td>
<td>
</td>
</tr>
</table>

Analysis:-

- A Touch display in the CS and very few buttons to control but display contained lofts of functionalities with small icons numbers and text
- The CS contained 3 control groups' media, climate and drive mode controls.
- Nice groupings & direct mapping
- The analog IC with small digital display in the center
- The SW has many shortcut buttons.

Moreover, the detailed analysis with the groupings of the functionalities is given below. Description of all the components in the dash board is listed in the figure 4.3. Here, highlighted features are those which comes under our scope of the project areas including instrument cluster, steering wheel and center stack.

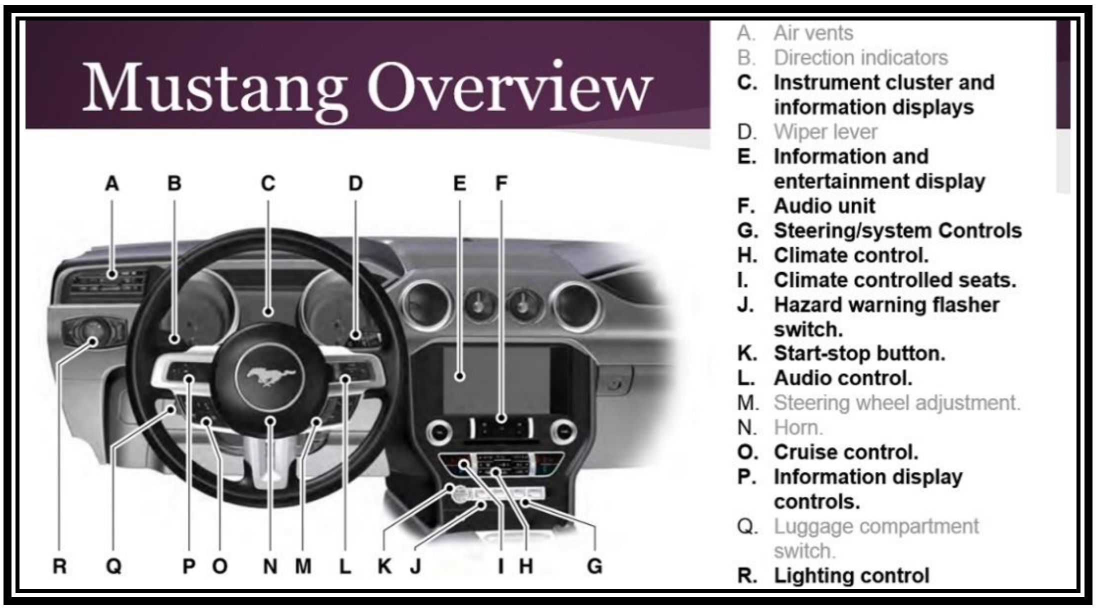


Figure 4.3: Ford Mustang Overview, 2015

Further, as interact by grouping is an inherited human capability, we grouped these features under six major categories as follows:

- Infotainment
- Navigation
- Climate controls
- Car systems
- Instrument cluster
- Steering wheel

These group are formed to compare the features in the respective group to the feature in the same group for the Chevrolet Camaro to reduce the complexity in the interaction design. The grouping and synthesis of the features is given in table 4.6 below.

Table 4.6: Ford Mustang Features and Grouping

Infotainment	• 8-inch touch screen that can displays up to 4 mini screens
	• Weather forecast & Weather map
	• Movie Listings
	• Sports
	• Oil Pressure and G-Force gauges
	• SYNC® with MyFord Touch®
	    • Hands-free calling
	    • Climate control
	    • Access to audio/radio
	• Shaker Pro Audio System with HD Radio Technology
	    • AM/FM
	    • Single CD/MP3 Player
	    • Heads-up display simulates brake lights, flashes on the windshield and audible warning

Navigation	• 3-D graphics
	• SiriusXM® Traffic and SiriusXM® Travel Link
	    • Combines Global Positioning System
	    • Voice guided turn-by-turn directions
	    • Gas location and prices

Climate Controls	• Automatic climate control
	    ○ Dual climate control
	• Manual controls
	    ○ Inside/outside air flow
	    ○ Fan Speed
	    ○ Seat warming
	• Rain-sensing wipers
	• Windshields defog

Car Systems	• Emergency light
	• Traction control
	• Start/Stop
	• Break assist
	• Forward collision warning
	• Steering and damper calibration
	• Adaptive Cruise Control
	• BLIS® (Blind Spot Information System)
	• Track App™
	    • Electronic Line-Lock: keeps front brakes locked while the car is in a gear to enable warming of the rear tires
	    • Launch Control

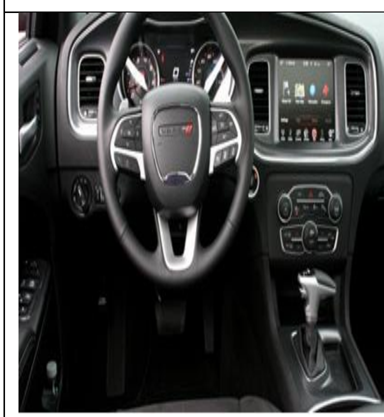
Instrument Cluster	• Speedometer • RPM meter • Vehicle Information menu (units, tire pressure, remaining oil life, coolant temperature, speed warning) • Trip/Fuel menu (digital speedometer, trip odometers, fuel range, average fuel economy, average vehicle speed, OnStar® Turn-by-Turn guidance) • Performance menu (lap timer, coolant temperature, battery voltage, oil temperature, oil pressure).
Steering Wheel	• 5-way buttons (access to six menu options on 4.2-inch center screen) • Adaptive cruise control • Redundant audio switches (volume, seek, media) • Call/hang up • Voice command activate • Mute

4.2.2 Dodge Charger

Dodge Charger is another muscle car and a second biggest competitor of General Motor's Chevrolet Camaro. Figure 4.4 shows the landscape of Dodge charger 2015 and Table 4.7 shows the detailed analysis of in-car interaction design.

Figure 4.4: Dodge Charger Land Scape, 2015

Table 4.7: In-Car Interaction Design Analysis of Dodge Charger.

<table>
<tr><td>Dashboard</td><td>Center stack (CS)/infotainment</td><td>Instrument-Cluster (IC)</td><td>Steering Wheel (SW)</td></tr>
<tr><td colspan="4">2. Dodge Charger</td></tr>
<tr><td></td><td>
</td><td>
</td><td>
</td></tr>
<tr><td colspan="4">Analysis:-
- A Touch display in the CS with single control in the middle of the center-stack.
-The display contained lofts of functionalities with small icons numbers and text
-The CS contained 2 control groups’ media and climate</td></tr>
</table>

-Nice groupings & direct mapping - The analog IC with small digital display in center - The SW has many shortcut buttons.

Similarly, the detailed analysis with the groupings of the functionalities is given below for the dodge charger. Description of all the components in the dash board is listed in Figure 4.5. Here, highlighted features are those which comes under our scope of the project areas including instrument cluster, steering wheel and center stack.

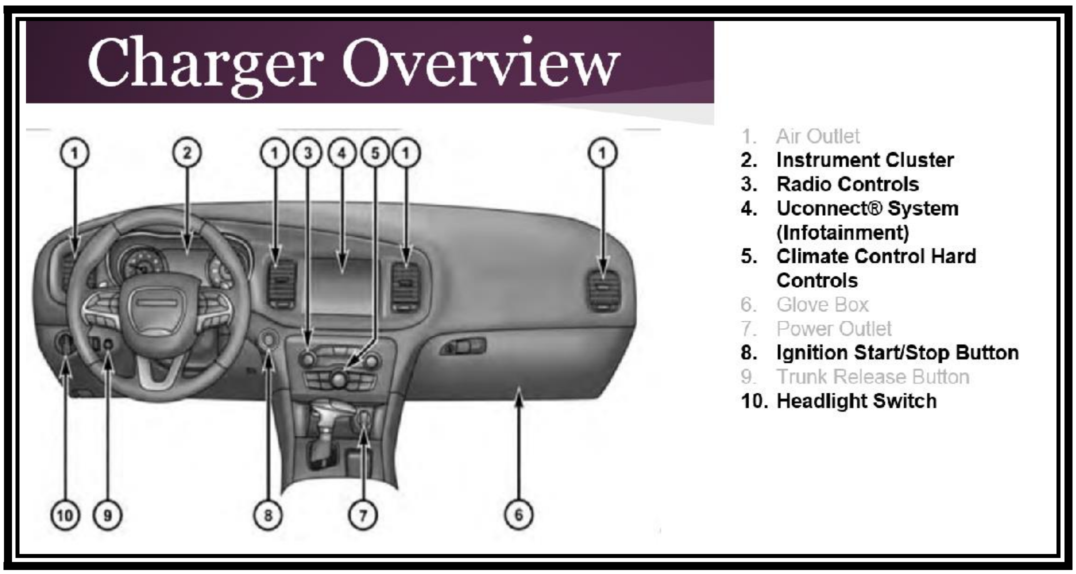


Figure 4.5: Dodge Charger Overview, 2015

These features are grouped by the six major categories discussed in the section 4.2.1 to compare the features in the respective group to the feature in the same group for the Chevrolet Camaro to reduce the complexity in the interaction design. Table 4.8 represents grouping and synthesis of the features.

Table 4.8: Dodge Charger Features and Grouping

Infotainment	• Weather forecast & Weather map
	• Movie Listings
	• Sports
	• AM/FM/SiriusXM® Satellite Radio
	• ParkView® Rear Back Up Camera
	• Uconnect Access
	    • Voice Command
	    • Radio presets
	• Keyless Enter 'N Go™
	• Phone
	• Wi-Fi hotspot (Uconnect access can operate as mobile for an additional monthly charge)
	• Bluetooth®
	• USB
	• SD card
	• AUX

Navigation	• 3-D graphics
	• Garmin® Navigation System with SiriusXM® Traffic and SiriusXM® Travel Link
	    • Gas station by brand, type, price, and distance
	    • Favorite places

Climate Controls	• Rain-sensing wipers • Dual-climate control • Airflow / Auto sync • A/C on/off • Front & Rear windshield defog • Headlight brightness and mode setting

Car Systems	• Drive modes access through STR button: custom, sport, track, default, eco • Start/Stop • Traction control • Park assist • Launch control system • Emergency light • Adaptive Cruise Control

Instrument Cluster	• 7-inch TFT configurable digital cluster display
	    • Oil/Water temperature gauges
	    • Performance (0-60 time, reaction time, etc.)
	    • Digital display of MPH
	    • Gear
	    • Digital compass
	    • Outside temperature
	    • Vehicle Information
	    • G-force meter
	    • Turn-by-turn navigation
	• RPM & MPH meters
	• Engine cooling temperature
	• Gas range

Steering Wheel	• Redundant audio switches (volume, seek, media) • Call/hang up • Voice command access • Cruise control, Cruise adjustment, adaptive cruise • Paddle shifters

4.2.3 Chevrolet Camaro

To preserve the brand value and the consistency in the design, the detailed analysis of Chevrolet Camaro 2015 is also done to come up with next generation (2020) Camaro. Figure 4.6 shows the landscape of Chevrolet Camaro 2015 and Table 4.9 shows the detailed analysis of interaction design.

Figure 4.6: Chevrolet Camaro Land Scape, 2015

Table 4.9: In-Car Interaction Design Analysis of Chevrolet Camaro.

Dashboard	Center stack (CS)/infotainment	Instrument-Cluster (IC)	Steering Wheel (SW)

3. Chevrolet Camaro

Analysis:-

-A Lower placed touch display in the CS with small manual buttons

- Less cluttered display as compared to two previous muscle cars

-The CS contains only one for the climate control, other manual buttons have no grouping.

- A Completely unpractical and very lower placed gauge indicators in the CS

-The analog IC with digital small display in the center

The detailed analysis with the groupings of the functionalities is given below. Description of all the components in the dash board is listed in Figure 4.7. The listing includes the areas our scope of the project areas including instrument cluster, steering wheel and center stack.

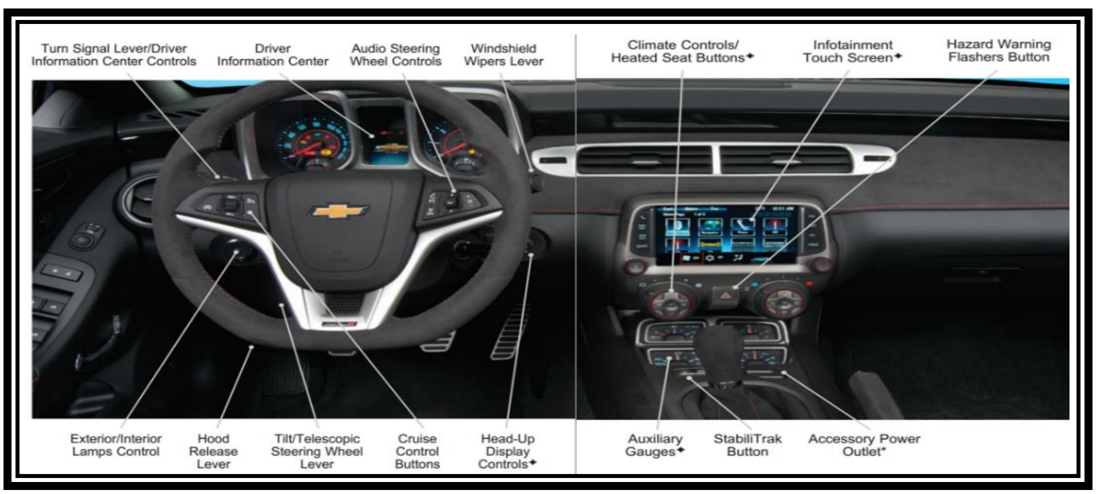


Figure 4.7: Chevrolet Camaro Overview, 2015

Further, these features are grouped by five major categories infotainment, navigation, climate controls, car systems and instrument cluster. These group are formed to compare the features in the respective group to the feature in the same group for the Chevrolet Camaro to reduce the complexity in the interaction design. The grouping and synthesis of the features is given in Table 4.10 below.

Table 4.10: Chevrolet Camaro Features and Grouping

<table>
<tr>
<td>Infotainment</td>
<td>

7-inch touch screen
Chevrolet MyLink
SiriusXM® Satellite Radio and SiriusXM® Travel Link

Nearby gas stations and fuel prices
Up to the minute weather reports
Movie times

AM/FM/CD
Rear Vision
4 Gauges

Oil pressure
Battery
Oil temperature
Transmission fluid temperature

Color heads-up display simulates speed, rpm, lateral g-force, radio station, etc.

Display height and intensity can be customized by the knob and button next to the steering wheel
AM/FM
Single CD/MP3 Player
Heads-up display simulates brake lights, flashes on the windshield and audible warning

</td>
</tr>
</table>

Navigation	• Navigation radio for the maps and directions • On Star® Turn-by-Turn Navigation • 3D Map • Voice input • Speed limit
Climate Controls	• Seats heater • Airflow / Temperature • Single climate control • Windshields defog
Car Systems	• Emergency light • Traction control • Start/Stop • Launch control (manual transmission only) • Drive modes

Instrument Cluster	• RPM/Speedomete
	• Digital compass
	• Fuel range
	• Trip range
	• Engine cooling temperature
	• Color Driver Information Center
	    • Tire pressure
	    • Gear
	    • Oil life
	    • Fuel range
	    • Oil Pressure
	    • Other vital stats

Steering Wheel	• Cruise control • Redundant audio switches (volume, seek, media) • Call/hang up, Mute

	• Voice command • Color driver information center control (located on the headlight knob)

4.2.4 Overall Close Competitors Analysis

From analysis in the section 4.2.1-4.2.3, pros and cons of the interaction designs can be listed as follows in table 4.11 below.

Table 4.11: Overall Close Competitors Analysis

Car	Pros	Cons
Ford Mustang	-Heads-up display	-Touch screen/toggle switches/many physical buttons = highly distractive
Dodge charger	-Touch screen/toggle switches/many physical buttons are highly distractive	-Drive modes “STR” button located in the horizontal center-stack, driver would have to look away from the road to access
Chevrolet Camaro	- Color heads-up display is customizable. - Driver information center is on the cluster -- less time away from the road	-Location of 4 gauges in the horizontal center-stack is almost impractical -- hard for the driver to see.

4.3 Remote Competitors Analysis

This class is to identify the overall market trends in the muscle car category that are not closely competing in the North American market. This section presents the analysis of the muscle cars in the remote markets, such as Japanese car Nissan GT-R 2015 and German cars, such as BMW M4 2015 and Mercedes Benz CLA45 AGM 2015. Table 4.12 shows detailed analysis of interaction design for the remote competitors.

Table 4.12: In-Car Interaction Design Analysis of Muscle Cars.

Dashboard	Center stack (CS)/infotainment	Instrument-Cluster (IC)	Steering Wheel (SW)
1. Nissan GT-R			
			
Analysis:- -A touch display in the CS and very few buttons to control but display contained lofts of functionalities with small icons numbers and text -The CS contained 3 control groups’ media, climate and drive mode controls. - Nice groupings & direct mapping -The analog IC with digital status sings - The SW with many shortcut buttons.			
2. Mercedes CLA45 AGM			
			

<table>
<tr><td colspan="4">Analysis:-
-A touch display in the CS at height in direct sight of driver
-The CS full of small buttons with two control groups together
-A Central controller to operate the display
-The analog cluster with small digital display in the center of IC</td></tr>
<tr><td colspan="4">3. BMW M4</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Analysis:-
-A Touch display in the CS at height in direct sight of driver
-The Secondary small display for the climate status.
-Nice grouping but again many small buttons, Media control group is moved to horizontal CS.
-The analog cluster with small digital display in center
-A SW with a lot of shortcut buttons.</td></tr>
</table>

4.4 Future Trend Analysis

After the analysis of the state of the art technology, analysis future trends is necessary to have the idea of where the automotive industry is heading in terms of smart car technology. It is sure that the smart cars are becoming more and more digital but the question is what could be the next generation interaction behind the wheels. Table 4.13 given below shows the analysis if in-car interaction design of future concept cars from different automakers.

Table 4.13: In-Car Interaction Design Analysis of Concept Cars.

Dashboard	Center stack (CS) /infotainment
1. Nissan Resonance Concept	
	
Analysis:- -A big touch display in the CS with full of small numbers, text, images, icons and menus -A display in the CS completely replaces manual knobs. -Unfamiliar shaper of display and no form and function principle -The IC is replaced with digital display and too much information on it -No shortcut buttons on the SW	
2. Nissan Friend-Me Concept	
	

Analysis:-

-A big touch display in the vertical CS but still icons are very small and cluttered with too much information

- An optional manual buttons and a single controller for the big display

-The IC is replaced with digital display

- No shortcut buttons on the SW

3. Hundai Blue-Will Concept

Analysis:-

- Supper big and fancy CS with small touch display and very small digital buttons and very inefficient use of space

-IC replaced with digital display but traditional odometer & speedometer gauges are replaced with digital number

-No shortcut buttons on the SW

4. Renault Fluence Concept

Analysis:-

- Infotainment & IC both combined in one long display with utilization of space.

-Touch display with iPhone like big icons

-The display is controlled from central controller in the horizontal CS.

-IC display is customized to display number instead of traditional gauges

- No manual buttons on the horizontal or vertical CS

-No shortcut buttons on the SW

5. Giugiaro Brivido concept

Analysis:-

-Upper CS is soft touch display climate controls for both driver and passenger separately

- Lower CS contained tactile hard buttons for a gear selection, traction control, and window controls

-IC is fully customizable gauge cluster controlled by soft touch buttons on the steering wheel

-Auxiliary display showing more in depth information about media, and car functions

-Digital “mirrors” are on both sides of IC for easy use showing rear view

6. Honda S2000 concept

Analysis:-

-An integrated phone control in the CS with multi-touch climate control above it.

- The IC contained 3 digital screens that appear to be customizable to see rear view but are currently set to media on the left, speed in center, and other car diagnostics on the right.

-Turning indicators are in the steering “wheel” at the natural thumb position.

-An unfamiliar design of the Steering wheel

7. Volvo You only concept

Analysis:-

-A similar UI as an iPhone in the CS

- A higher placed screen with big icons

- Has a single big home button in the CS

- Nice use of space and swallow outside to zoon in the selected icon

-The IC is less crowded and no change in the traditional gauges

8. Renault Ondelios

Analysis:-

-CS is full dash display with navigation, menu selections, and climate controls but full of small icons

<table>
<tr><td colspan="2">-Passenger and driver climate controls are separate
-IC is full digital “hologram” displaying speed and gear selection
-Full keyboard available while parked</td></tr>
<tr><td colspan="2">9. Mercedes-Benz Futur truck concept</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td colspan="2">Analysis:-
-The CS is removable display with very few manual control buttons
-The display has very clear interface with big icons and very good grouping
-The IC is fully digital displaying with option of analog like gauge layout selection
- The SW design is also clear and has only useful shortcut buttons.
-Overall in-car dashboard design is good and interaction seems to have improved a lot</td></tr>
</table>

4.5 Quantifying the Interaction Complexity in the Centre-Stack

Previously, there were no concrete metrics known to measure the interaction complexity in the center-stack. For the study purpose, we devised and simplified the way to measure the interaction complexity in the center-stack. From the rigorous analysis done in this chapter, metrics are presented in Table 4.14, to realize the complexity of interaction in the cars today. The metrics show the number of hard buttons in the center-stack, which includes all the physical (manual) buttons, such as squared, rectangular, and rounded buttons, knobs, horizontal and vertical sliders, and multi-purpose buttons. It also shows, the Max number of Soft buttons in a typical screen in the center-stack, which includes the rounded, squared and rectangular touch buttons, touch icons, radio buttons, and menus. The rage of the size of hard and soft buttons was derived by smallest and largest among them. Last column of the metrics shows the total no. of input buttons including hard and soft buttons a driver has to deal with, while interacting to the center-stack. Clearly, these metrics covey the complexity of interaction in the center-stack of today's smart cars.

Table 4.14: Interaction Complexity in the Center-Stack.

Car	**No. of Physical Buttons in the Center Stack (CS)**	**Typical Range of the Size of the Hard Buttons in the CS (in Inch)**	**Max. No. of Soft Buttons (icons) in a Typical Screen in the CS Display**	**Typical rage of the size of the Soft Buttons (icons) in the CS Display (in Inch)**	**Total No. of Input Buttons (hard and Soft) at a Times in the CS**
Economy Cars					
Kia Rio	23	0.5"- 1.25"	15	0.5"- 2"	40
Ford Focus	24	0.25"-1.25'	19	0.5"- 2"	43
Ford Fiesta	38	0.25"- 1"	19	0.5"- 2"	57
Toyota Corolla	21	0.5"-1.5"	19	0.25"- 1.75"	40
Honda Accord	20	0.5"- 1.25"	8	0.25"- 1.5"	28
Volkswagen Polo	26	0.5"- 1.25"	12	0.25"- 1.5"	38
Nissan Versa	28	0.5"- 1"	8	0.5"- 2"	33

Chevrolet Malibu	31	0.25”-1”	14	0.5”-1.25”	45
Premium Cars					
Ford Taurus	23	0.25”-1.25”	19	0.5”- 2”	42
Toyota Avalon	27	0.5”-1.5”	19	0.25”- 1.75”	46
Acura TLX	19	0.5”- 2”	20	0.5”- 2”	39
Audi A4	24	0.5”-1.5”	9	0.5”-1.5”	33
BMW 3 Series	34	0.5”-1.25”	10	0.5”- 1”	44
Cadillac CTS	24	0.5”-1”	11	0.25”-1.5”	35
Volvo S80	34	0.75”-1.25”	8	0.25”-3”	42
Chrysler 300	16	1”-1.5”	16	0.5”-1.5”	32
Chevrolet Impala	21	0.5”-1”	14	0.5”-1.5”	35
Sports Cars					
Ferrari 458	30	.075”-1.5”	-	-	30
Bentley	27	0.5”-1”	12	0.5”-2”	39
Jaguar XF	26	0.75”-1’	12	0.5”-1.75”	38
Lamborghini Aventador	35	0.5”-1.5”	9	0.25”-1.25”	44
Maserati Gran-Turismo	14	0.25”-2”	23	0.5”-1.5”	37
Bugatti Veryon	16	0.25”-1”	-	-	16
Chevrolet Z06	26	0.5”-1”	14	0.5”-1.5”	40

Luxury Cars					
Tesla Model S	-	-	37	0.25”-1.5”	37
Porsche	38	0.5”-1.75”	11	0.5”- 2.5”	49
Mercedes-Benz S Class	18	0.5”-1”	14	0.5”-1”	32
BMW 7 Series	32	0.5”- 2”	10	0.25”-2”	42
Audi 8	24	0.5”-1.5”	9	0.5”-1.5”	33
Audi TT	8	0.5”-1.5”	14	0.25”-.075”	22
Lexus LS	23	05”-1.25”	21	0.25”- 1.75”	44
Rolls Royce	33	0.25”-1.25”	16	0.25”-1.5”	49
Muscle Cars					
Ford Mustang	24	0.5”-1.5”	19	0.5”- 2”	43
Dodge charger	16	0.5”-2”	20	0.5”-1.5”	36
Chevrolet Camaro	18	0.5”-1”	14	0.5”- 2”	32
Nissan GT-R	32	0.25’-1.5”	12	0.25”-	44
Mercedes CLA AGM	36	0.5”-1”	8	0.5”-1”	44
BMW M4	32	0.5”-1.25”	10	0.5”- 1”	42

CHAPTER 5

5. MULTI-MODAL INTERACTION SYSTEMS (MMIS)

Multimodal interaction refers to the "interaction of humans with physical environment through natural modes of communication", which means the modes involving the five human senses [Bourguet 2003]. This chapter presents current multimodal interaction system in HCI and proposes enhanced version of multi-modal interaction system for the HCaI. The chapter ends with the discussion about the advantages of such systems in all the aspects of the HCaI. There is a thin line between a multimodal interface and a multimodal interaction. It can be defined as follows.

- Multimodal interface: - "An interface that processes two or more combined user input modes in a coordinated manner to produce the multi-media system output". It is a new class of interface that aim to recognize naturally occurring human language and behavior and which incorporate one or more recognition technologies (such as touch, speech, pen , vision, haptic) [Oviatt 2002].
- Multimodal interaction: - The situation where user is provided with the multimodal interface for interacting back and forth with a system using a combination of these two or more modes to accomplish a task.

5.1 Multi-Modal Interaction Systems in HCI

In Multimodal human-computer interaction (MMI), the modes involved in the interactions are the five major human senses including sight, hearing, touch, taste, smell but not limited to them. Human perceive the outer world through these senses (sensory input) and act on it through the motor control of their effectors [Ferri 2009]. The effectors includes limbs (arms, legs, and body position), fingers, eyes, head (face), body and vocal system. This implies that multimodal interaction enables a more free and natural way of communication. The growing interest in a multimodal interaction design is inspired largely by the goal of supporting natural and human way of interaction with more transparent, flexible, efficient, and powerfully expressive means of human-computer interaction [Stivers 2005]. Multimodal interaction is also expected to be easier to learn and use as it supports and mimics the human way of interaction using the senses.

5.1.1 Fusion of Input Modalities in the MMIS

The first group of interfaces combined various user input modes beyond the traditional keyboard and mouse inputs/outputs, such as speech, pen, touch, manual gestures, gaze and head and body movements. The process of integrating information from various input modalities and combining them into a complete command is referred as Multimodal fusion [D'Ulizia 2009]. The most common such interface combines a visual modality (e.g. a display, keyboard, and mouse) with a voice modality (speech recognition for an input, speech synthesis and recorded audio for an output). However other modalities, such as pen-based input or haptic input/output may be used. In the literature, three main different approaches to the fusion process have been proposed, according to the main architectural levels (recognition and decision) at which the fusion of the input signals can be performed: 1) recognition-based 2) decision-based and 3) hybrid multi-level fusion.

- The recognition-based fusion [Vo MT 1998] (also known as early fusion) consists of merging the outcomes of each modal recognizer by using integration mechanisms, like statistical integration techniques, agent theory, hidden Markov models, artificial neural networks, etc. Examples of recognition-based fusion strategies are action frame, input vectors and slots.
- The decision-based fusion [Bouchet 2004] (also known as late fusion) merges the semantic information that are extracted by using specific

dialogue-driven fusion procedures to yield the complete interpretation. Examples of decision-based fusion strategies are typed feature structures, melting pots, semantic frames, and time-stamped lattices.

- In the hybrid multi-level fusion [Reitter 2004], the integration of input modalities is distributed among the recognition and decision levels. The hybrid multi-level fusion includes the following three methodologies: finite-state transducers, multimodal grammar and dialogue moves.

5.1.2 Fission of Output Modalities

A multimodal system should be able to flexibly generate various presentations for the same information content in order to meet the individual user's requirements, environmental context, and the type of task and hardware limitations. Adapting the system to combine these time changing elements is known as Multi-modal Fission [Ismail 2008]. The second group of multimodal systems presents users with multimedia displays and multimodal output, primarily in the form of visual and auditory cues. When multiple output modalities, such as text-to-speech synthesis, audio cues, visual cues, haptic feedback or animated agents are available, output selection becomes a delicate task to adapt to a context of use (e.g. car, home, work), type of task (e.g., information search, entertainment) or type of user (e.g. visually impaired, elderly). Fission techniques allow a multimodal application to generate a given message in an adequate form according to the context and user profiles. Technically speaking, fission consists of three tasks:

- Message construction, where the information to be transmitted to the user is created; approaches for content selection and structuring revolve mainly around either schema-based approaches or plan-based approaches.

- Output channel selection, where interfaces are selected according to context and user profile in order to convey all data effectively in a given situation. Characteristics, such as available output modalities, information to be presented, communicative goals of the presenter, user characteristics and task to be performed, are forms of knowledge that can be used for an output channel selection.
- Construction of a coherent and synchronized result: when multiple output channels are used, layout and temporal coordination are to be taken into account. Moreover, some systems will produce multimodal and cross-modal referring expressions, which will also have to be coordinated.

Interface designers have also started to make use of other modalities, such as touch and olfaction. Proposed benefits of multimodal output system include synergy and redundancy. The information that is presented via several modalities is merged and refers to various aspects of the same process. The use of several modalities for processing exactly the same information provides an increased bandwidth of information transfer. Currently, multimodal output is used mainly for improving the mapping between communication medium and content and to support attention management in data-rich environment where operators face considerable visual attention demands.

5.2 Supporting Technologies for the MMI in HCaI

Multimodal interaction is a new term when it is used in the context of automobiles but has been widely used in HCI since early nineties. In this thesis, we identified new modes of interaction which are different from human computer interaction modes. Automotive environment is dynamic and it has the different set of challenges regarding cognitive load, driver distraction. The smart cars use the sophisticated technologies, such as voice recognition, high definition graphics displays, high sensitive and multi-touch displays, haptic technology to provide haptic feedback, ambient lightening, hand-gesture input, gaze detection and pen-based input. But the use of complex software as a medium of interaction has made the interaction even more complex than the simple unimodal interaction using manual buttons. As described in section 3.2 (p.35-39), researchers have proved that speech-based interaction with in-vehicle information systems demands attention and can distract drivers and degrade safety. Designers should recognize that speech-based interaction draws upon some of the same cognitive resources as driving does and, so, can distract drivers just as visual displays and manual controls can [Kern, Schmidt 2009]. Subjective measures of workload and distraction suggest that increasing the complexity of a speech-based interface may impose a greater cognitive load. However, it can be argued that attaining perfection in speech-recognition is not the answer but there is need of an enhanced MMIS, specially for the smart cars what we need is to design an easy to use and learn interaction with the use of latest technology in the market. The supporting technology in today's smart cars for the input and out modalities are discussed further in this section.

5.2.1 Input Modalities in the HCaI

Despite the high variation of different arrangements of car cockpits, the number of installed input devices in all cars is limited to a few standard controls. There are different input possibilities, which are illustrated in the table below. New interaction techniques like speech and gesture recognition, as well as indirect interaction like fatigue detection using an eye tracker or cameras, have also found their way into the car. In Contrary to the arrangement of input devices in the desktop domain, all devices in the car have to be mounted in fixed positions. Controls have to be always at the same position so that the driver can easily find them without having to take his eyes off of the road. To further help the driver focus on the road, blind interaction through haptic feedback is a research area worth pursuing. Another key aspect for the positioning of an input and output devices is the limitations due to ergonomic factors. All input devices have to be within the driver's reach, so that s/he can safely manipulate them with either hand or foot while driving. Figure 5.1 shows the common input modalities for the in-car interaction [Kern, Schmidt 2009].

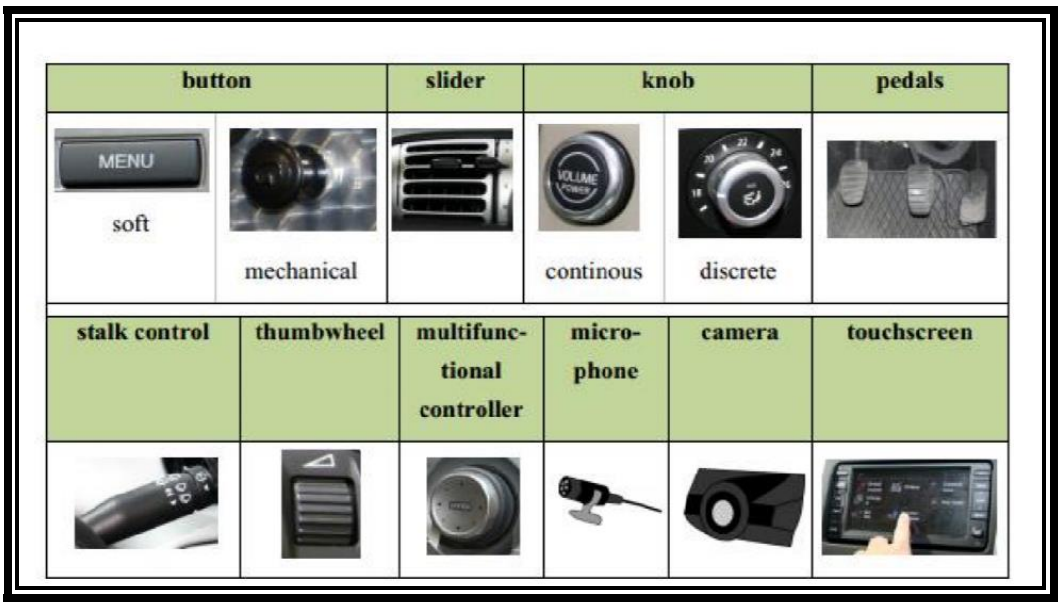


Figure 5.1: Input Modalities in the HCaI

5.2.2 Output Modalities the HCaI

Output devices in cars are used to provide feedback to the user about the current state of the system, e.g. about the current speed, if the turn signal is turned on, or which radio channel is currently playing [Kern, Schmidt 2009]. The output modalities are limited by the human senses, specifically sight, hearing, touch and smell. The primary driving task itself is very demanding on the sense of sight. Any additional visual information forces the driver to draw his attention away from the road scene and that may lead to critical situations.

Figure 5.2 shows the different output modalities that can be found in nearly all the cars that we analyzed. There are a lot of visual indications available in the car to give feedback about current functional states. These indications vary from simple indicator lamps to high-resolution displays. Visual representations are also used to present information that is directly correlated to the driving task, e.g. actual speed. Both analog and digital representations are used for these purposes. Analog representations can also be divided into displays that use a physical dial and pointer and displays that replicate the dial and pointer virtually. Virtual representations allow for more dynamic use of the space in the middle of the dial to show other information. Digital displays have been used since the end of the 1970s to show alphanumerical information, e.g. the current radio channel or traffic information. These systems are controlled by buttons on each side of the screen, a central controller or touchscreen. A further development of display technology in the car is the introduction of head-up displays (HUDs) that show driving related information directly in the driver's field of view. The visual output appears slightly in front of the car even though it is technically a projection on the windshield. The sense of hearing is addressed by loudspeakers, which are integrated into the car or embedded in an external device, e.g. a portable navigation system. This modality has long been used for entertainment purposes and has more recently been used for giving aural feedback, especially with voice-operated systems. Due to the arrangement of loudspeakers in some cars, it is possible to provide spatial information over this channel as well. For example, while driving in reverse, an obstacle on the left side could be indicated by sounding a beep from the rear left side.

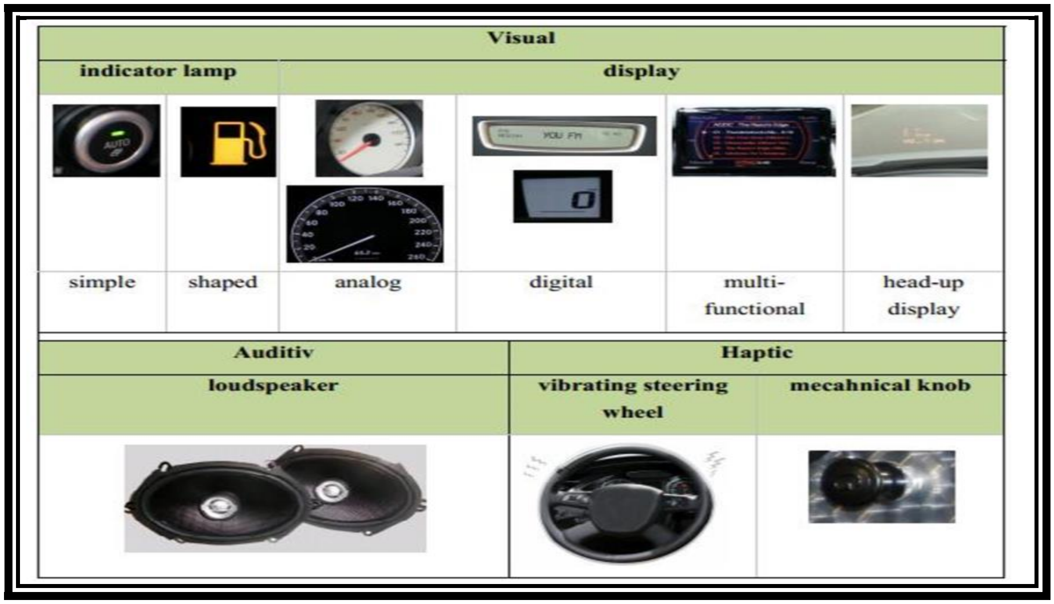


Figure 5.2: Output Modalities in the HCaI

Information can also be delivered to the driver through his sense of feel or touch. Recently, some car manufactures have added vibration feedback to the steering wheel or to the driver's seat to warn the driver, e.g. of lane departures when no turn signal has been made.

5.3 Proposed Enhanced MMIS to Reduce Driver Distractions

From the extensive analysis of smart car environment in chapter 4, it is evident that we cannot replace manual buttons completely with touch or voice interaction. Subsequently, we proposed the enhanced MMIS for the smart cars. It is mainly categorized into four modes based on the types of interaction including 1) visual, 2) touch, 3) speech interactive and 4) learning mode.

1. Visual Mode: - Some of the manual buttons can be just avoided because of the accessibility it provides to the driver so we introduced a visual mode of interaction. The "Visual" mode can be simply understood as exact virtualization of hardware on the infotainment screen. User is allowed to give input as speech or touch the application icon, based on that either the action is performed or hardware image is displayed. This gives user the flexibility to use any car system without taking eyes off the road and hence, minimizing distraction.
2. Touch Mode: - The "Touch" mode allows user to physically touch an icon present on the high definition graphics display in the center console. From the trends analyzed for the smart cars, it is evident that infotainment without touch display is not a new thing anymore. But these displays are providing lots of unnecessary information through lots of small icons, menus, and tiny status bar. The proposed touch interaction follows the minimalistic design principle, displaying highest priority information first with big icons and proper use of space following layered hierarchy. Thus, enhanced touch mode provides an interface which is clear, easy to learn and less distractive in terms of usability. The example of proposed design is given at end of this section.
3. Speech Interactive Mode: - This mode is designed to provide interactive and less distractive experience without taking hands away from steering wheel and eye off the road. The "Speech Interactive" mode, as the literal meaning suggests is nothing but interaction with the car using speech. For a speech input, user can expect to have a speech output. As mentioned in section 3.2.3 researchers have proved that speech recognition increases the cognitive load, the solution would be to keep the grammar as simple as possible. Opposed to the current faulty voice interaction systems in smart cars it does not come with natural language

speaking because from analysis on in-car voice interaction in chapter 3, it is evident that natural speech recognition is not feasible due to challenges related to hardware limitations and environment noise. So, proposed mode comes with limited and useful speech commands and the system responds back to the commands interactively. The MMIS covers learning mode which trains the novice user and also learns from the user speech interaction. Once the user knows the interface very well, the system can be customized to fully speech interactive mode.

4. Learning Mode: - Though the human way of interaction is the implicit nature of ours, the term multimodal is not that much known specially for the in-car interaction. Also, to support faster learning curve and to improve system usability, a fourth mode is added as learning mode. The “Learning” mode allows user to get trained with respect to the multimodal functionalities while experiencing less cognitive challenge. For example. If a user touches any icon then system will echo the speech command corresponding to that icon. Therefore, s/he learns how to and which command is to be used exactly for what functionality and hence it improves the efficiency as well as reduces the cognitive load. Also, in a case where user intends to do something and speaks the wrong command, the system will respond interactively with available alternatives. For example : If the user says, “Play track 15 by Enrique”, but this command is not acceptable by the dialogue system then the MMIS will check all possible options and will speak back to the user. This way user will get to learn the commands. This mode can be turned on and off as per the user convenience.

5.4 Prototype Design of Proposed MMIS for the HCaI

The MMIS can be designed to support simultaneous use of input modes, to permit switching among modes to take advantage of the modality best suited for a task, environment, or user capabilities. It can also “translate” information from one mode to another in order to expand accessibility for the users with selective limitations.

The main goal of coming up with enhanced MMIS is to reduce distraction by minimizing the interaction time with the car systems. Hence, the MMIS user interface is a hierarchical structure that requires 1 click per screen and at most 4 clicks in form of touch interaction to perform an operation correctly. Similarly, in term of speech interactive mode, structure provides access to functionalities with at least 1 command to at most 4 commands. As the human eye perceives images faster than text, we have designed big icons layouts without text which requires minimum thought process. There is a home icon at the bottom of every screen which actually, would be implemented as a built-in button in the hardware itself. On clicking on the home button, the screen will go back to the home screen. Hence, providing highest accessibility to any other function at any given point of time while interacting with the MMIS. The UI design prototype of the proposed MMIS in the HCaI is given in APENDIX B.

5.5 MMIS Advantages

As applications in smart cars have generally become more complex. A single modality does not permit the user to interact effectively across all tasks and environments [Oviatt 1999]. Since individual input modalities are well suited in some situations, and less ideal or even inappropriate in others, modality choice is an important design issue in a multimodal system. Also, an individual modalities are not good at handling unexpected frustration arising from system behavior as it doesn't provide any other alternative mode of interaction at the same time. Followings are the advantages of a MMIS user interfaces.

- A multimodal interaction offers the user freedom to use a combination of modalities, or to switch to a better-suited modality, depending on the specifics of the task or environment.
- Can accommodate a wider range of users, tasks, and environmental situations — including users of different ages, skill levels, native language status, cognitive styles, sensory impairments, and other temporary or permanent handicaps or illnesses. For example, a visually impaired user may prefer speech input.
- Can support less diffluent, shorter, and more linguistically-simplified constructions than a speech-only interface, which may results in more robust and efficient language processing.
- Satisfy higher levels of user preference and Support enhanced error avoidance and ease of error resolution. Adaptable during the continuously changing environmental conditions of mobile use.
- Accommodate individual differences, such as permanent or temporary handicap.
- Compared with speech-only interaction, empirical work with users during visual-spatial tasks has demonstrated that multimodal pen/voice interaction can result in 10% faster task completion time, 36% fewer task-critical content errors, 50% fewer spontaneous dis-fluencies, and also shorter and more simplified linguistic constructions with fewer locative descriptions [Oviatt 1999].
- MMIS supports superior error handling, compared with unimodal recognition-based interaction, both in terms of error avoidance and graceful recovery from

errors. The users have a strong tendency to switch modes after system errors, which facilitates error recovery [Oviatt 1999].

- Since there are large individual differences in ability and preference to use different modes of communication, a multimodal interface permits the user to exercise selection and control over how they interact with the computer [Karsh 1998].

CHAPTER 6

6. ADVANCE DRIVER ASSISTANCE SYSTEMS (ADAS)

As classified in chapter 1.3, this chapter covers the analysis of the ADAS in smart cars and Autonomous driving cars. These assistive technology helps the driver to make driving easier and safer. The challenge is to make the driver aware of the assistive technology and its features in the car and also provide an easy way to interact with them without getting distracted. This chapter provides the classification of ADAS, related technology, and introduces the autonomous driving.

In context to the Multi-Modal interaction, it is required that we virtualize all of the available Manual button related to ADAS as well. The broad classification of ADAS systems presented by DERSEV is given this section. It is classified in 10 groups with each group having several applications that are currently available or will be soon introduced in the automotive market. Thus, while designing the enhanced MMIS, it is desirable that the most of the manual buttons for this application can be virtualized as well as the easy to identify interaction is provided to get the best out of these assistive technology. The classification of ADAS is as follows:

6.1 Lane Change Assistance Systems

This category of ADAS includes Lane Departure Warning System (LDWS), Lane Change Assistance System (LCAS), Overtaking Assistance System, and Blind Spot Detection (BSD).

6.1.1 Lane Departure Warning System (LDWS)

At the end of a long drive back from our holiday or after a nerve-wracking, exhausting day at work, sleep creeps up on us almost unobserved and we are notoriously at risk of falling asleep for a few seconds. Drowsiness is a factor in roughly one in four severe accidents, mainly at night when the possibility of an accident is twice as great as by day. This is just one of the worst circumstances when the system can help, but there are many more scenario which can bring a car close to a accidental leaving of the lane – at the end this could be as risky as falling asleep. LDWS signals the driver with acoustical or haptic warnings before his vehicle is about to leave the lane. According to a study carried out on behalf of the Federal Ministry of Education and Research, LDWS could prevent just about half of the accidents caused in this way. Figure 6.1 shows the LDWS working through the sensors.

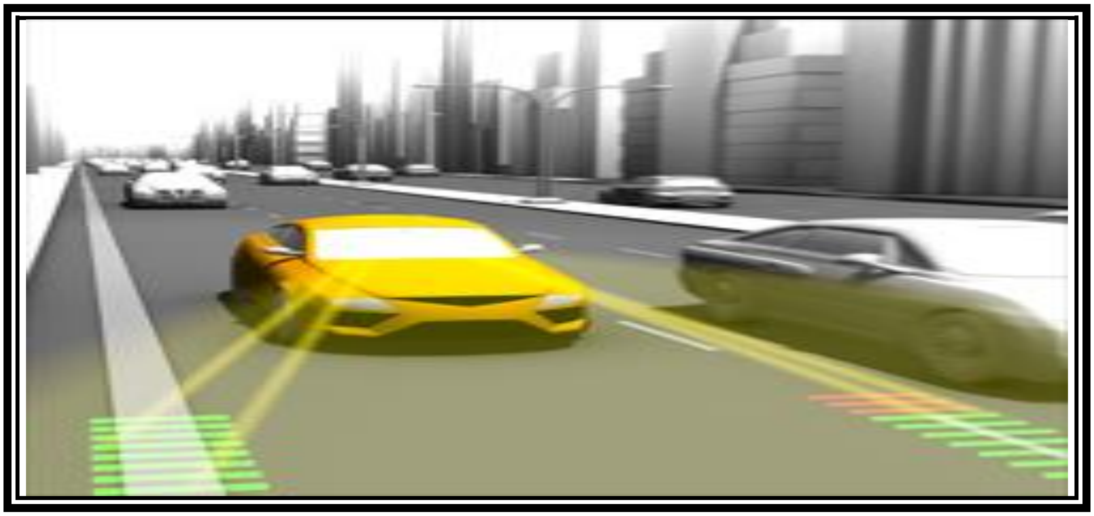


Figure 6.1: Lane Departure Warning

LWDS uses sensors behind the front bumper to monitor the lane markings, three on each side. When the sensors notice that the car is wandering across the lane markings and the indicators are not in use, typically a computer sends a signal to a pair of vibration devices, on each side of the driver's seat. If the car is wandering to the right, the driver senses a vibrating signal in the right side of the seat and vice versa. Thus, the warning allows the driver to take instant actions and navigate back to the lane. Moreover, the Lane Keeping System (LKS) responds through a gentle intervention in the steering, which the driver can counteract at any time. This can save extra time to react properly where each and every second counts.

LDWS are available in many cars today. One example is Audi A4 lane assist system. The steering wheel vibrates once only in order to aware the driver when the vehicle is approaching or crossing a spotted lane marker. The second warning is given only if the vehicle has moved an adequate distance away from the lane marker. There is a warning lamp on the dash panel. If the warning lamp is lit green, the system is active and "on alert". The system can be deactivated by the driver.

Figure 6.2: LDWS Info on the Instrument Panel of Audi A4

In addition to the audible and visual signals, LCAS actually can step in and helps steer the car back on course. This steering capability is relatively limited. The aim is not to take over the steering. Instead, the maneuvering is usually sufficient to help the driver take action to keep the vehicle within the current lane. These system are also provided on the market e.g. by Continental and Bosch. The above described Systems can be realized with the following technologies.

- Multi-Function Mono Camera – MFC: MFC increases comfort through recognition of traffic signs and lanes as well as controlling the high beams, therefore relieving the driver from strain.

- Multi-Function Stereo Camera – MFS: MFS makes the recognition of 3D objects possible and extends the emergency brake assistant function with pedestrian recognition. Forms the basis for the premium functions for an adaptive control of the chassis (e.g. magic carpet).

6.1.2 Blind Spot Detection (BSD)

Generally, a quick look at the inside and outside mirrors, possibly even a momentary glance over the left shoulder, we pull out to overtake and then a major fright happens when there is loud hooting from our left. As we fail to see the car approaching quickly from behind in the left-hand lane or in the blind spot next to our own car easily happens, particularly in a heavy traffic on the multi-lane freeways or highways and in urban traffic as well. The Blind Spot Detection System (BSDS) can monitor this area and take much of the worry off the driver and avoid dangerous situations. Blind spot detection warns the driver about cars that are approaching from the rear or cars that the driver is currently overtaking. The system uses a camera in each rearview mirror and these cameras are pointed at the so called Blind Spot, meaning the area alongside of the car which is hard to monitor by the outside mirrors. When another vehicle enters the monitored zone, a lamp comes on, in the relevant mirror. The driver gets a clear indication that there is another vehicle in the risk zone and can keep away. The system provides information about cars approaching from the rear and also vehicles in the front that the driver is currently overtaking. This information gives the driver added scope for taking the right decision in such situations. Both sides are monitored in the same way. The system is designed to alert the driver to vehicles that are moving a minimum of 20 km/h slower and a maximum of 70 km/h faster than the driver’s own vehicle. This system can now be found in the cars, such as new Volvo S80, XC90 and V70.

The above described function can be realized with the following technology.

Short Range Radar – SRR: SRR monitors the blind spot as well as the area behind the vehicle and can therefore help to prevent accidents when changing lanes or when reversing out of a parking space.

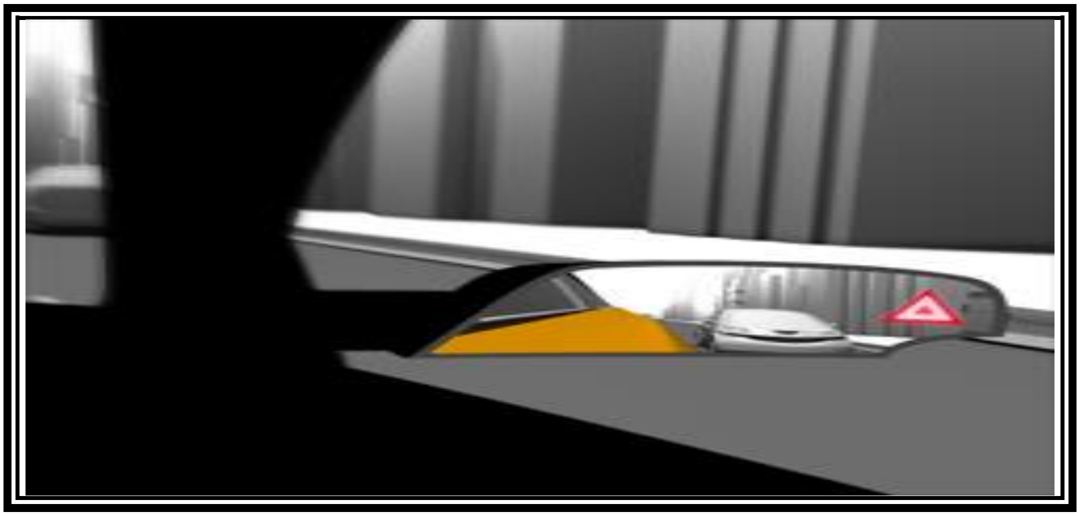


Figure 6.3: Blind Spot-Detection Using Short Range Radar

6.2 Forward or Rearward looking Systems

Forward/Rearward looking system include a wide range of ADAS; i.e. Collision Warning System, Low Speed Collision Avoidance System, Pre Safe System, Collision Avoidance System, Emergency Braking ahead, Electronic Emergency Brake Light, Intelligent Intersection (Emergency Vehicle Detection), Rear Approaching Vehicle, End-Of-Tail Congestion Warning. In this paragraph the most widespread HMI solutions for these systems are presented.

Collision warning and avoidance is a set of direct supports to the driver to assist safer driving. It covers two distinct sets of applications:

6.2.1 Collision Warning Systems: Pedestrian Detection System (PSD)

Collision warning systems provides information about possible collision to the driver, but it remains up to the driver whether to use that information and what action to take. Pedestrian Detection System supports drivers to identify a person near or on the road. These systems have to work in all whether conditions and at night. Also, they must be potent enough to differentiate pedestrians from other objects near the road. One example is BMW Pedestrian Warning system. It works during the day and uses a standard camera but will also apply brakes in case of an emergency, to avoid collisions. The system can be deactivated manually. If the system is active, the driver can see a check mark next to its icon. A camera feed on car's navigation screen is triggered pressing a button located under the lights switch, to the left of the steering wheel. If a pedestrian come in the car’s path, the driver receives an audible and visual important warning in the instrument cluster. Figure 6.4 shows the BMW PDW on the instrument cluster.

Figure 6.4: Pedestrian Detection Warning in the Instrument Cluster

Similar, these systems are present in Mercedes S class (Night view assist plus, for the pedestrian and the large animals detection) and in new Volvo series (new Volvo V40, S60, V60, XC60, V70, XC70 and S80) with cyclist detection technology.

6.2.2 Collision Avoidance Systems: - Emergency brake assistance (EBA)

These systems activates an avoidance reaction (e.g. deceleration) when a latent collision is detected. The majority of all rear-end collisions could be circumvented or at least, their harshness could be considerably reduced through timely braking. If the car approaches an obstacle (stationary or moving) and the driver does not react, a warning light activates and is reflected in the windscreen. At the same time, an audible buzzer sounds and a brake function is automatically activated to build up higher braking pressure. In certain situations, this is sufficient to catch the driver's attention and avoid the hazard. Some cars also tightens the seat belts, adjusts seat positions including rear seats (if installed) and can also close any open windows and the sunroof if necessary. Finally, where available, emergency braking intervenes automatically (e.g. Audi braking guard, Honda: Collision Mitigation Brake System). In addition to warning the driver to take action, the brake system can be readied to provide maximum brake boost once the driver does engage the brakes enabling reduced stopping distances. When the driver brakes, the system monitors the pedal pressure. If the pressure is too light for the car to be able to stop in time, the system steps in and amplifies more braking power. In case of Rear Pre Crash Safety System a millimeter-wave radar device in the rear bumper detects a vehicle approaching from behind. If the system determines a high possibility of collision, the hazard lights flash to warn the driver of the rear vehicle. And if the system determines a further increase in the possibility of a collision, it automatically activates the front-seat Pre-Crash

Intelligent Headrests, which shift to appropriate positions prior to impact to reduce the risk of whiplash injury. Figure 6.5 shows the EBA sensors monitoring forward vehicle.

Figure 6.5: Emergency Breaking Assistance

The EBA feature is also available in the different configurations. The rear-end collisions mostly occur in inter-urban areas. The EBA-City, an entry-level version, can prevent accidents in these areas at speeds of up to 25 km/h. The above described function can be realized with the following technologies.

- Multi-Function Camera with Lidar – MFL: The fusion of the mono camera and LIDAR can avoid rear-end collisions with a speed difference of up to 50 km/h. Through the redundancy of two technologies, safety is furthermore enhanced by the distinct identification of obstacles.
- Short Range Lidar – SRL: The SRL sensors are used for EBA and is already establishing itself in the compact car segment. It is fitted behind the windshield and monitors the traffic ahead. With the “EBA-City”

functionality it can avoid rear-end collisions in urban settings – in the speed range of up to 50 km/h at a difference of up to 25 km/h.

6.2.3 Rear Cross Traffic Alert (RCTA)

The Rear Cross Traffic Alert (RCTA) system uses the same radar infrastructure used for sensing the vehicles in the BSD and can help to circumvent accidents when withdrawing out of a parking space. Sometimes, these can even lead to serious accidents involving personal injuries. Figure 6.6 shows the RCTA sensing while reversing from a parking space.

Figure 6.6: RCTA Sensing While Reversing

This system uses two short-range radar sensors with which each monitoring a 120 degree angle. If the system detects a potential collision, a warning will sound and LEDs will light up in the interior rear view mirror to alert the driver. A possible action could also be for the vehicle's brakes to be automatically applied. The warning strategy employed can of course differs by the vehicle manufacturer. The precise data on the crossing vehicle's direction, being able to reliably calculate the collision trajectory of the crossing vehicle, speed and how far away it is, however, is required.

6.3 Cruise Control Systems

The Cruise Control Systems include the fully Adaptive Cruise Control (ACC) system and the ACC with Stop & Go.

6.3.1 Adaptive Cruise Control (ACC)

In the past, the car drivers all over the world enjoy relaxed driving by setting the adaptive cruise control on the empty roads and not having to concentrate on the tiresome process of maintaining the car's speed. But over the past 30 years traffic density has increased exponentially, and few opportunities remain for the drivers to enjoy the driving comfort offered by cruise control. That all has changed with new Adaptive Cruise Control (ACC), which can not only maintain the a speed chosen by driver, but also monitors and controls the distance to the vehicle ahead of the car on the motorway or a country road. Figure 6.6 shows the ACC sensors monitoring the vehicles ahead on a traffic road. While driving at a lower speed, the moment another vehicle ahead is within a certain distance, long range radar mounted in the front detects the situation and ACC adjusts the distance by braking the car the exact amount that's needed when activated, ACC give gas and to some extent applies the brake in a way to keep as high comfort as possible. Figure 6.7 shows ACC sensors monitoring the vehicles ahead.

The amount of power applied on the brakes is limited to a comfortable level that corresponds to a car deceleration. The driver is however always free to take over the control at any time or apply the brakes himself. This is certainly necessary whenever the system touches its limits, since it is the driver's responsibility to maintain in and for his car. If a situation arises that needs the system to apply the brakes the maximum amount, the driver is alerted accordingly by a light and sound.

To activate ACC the driver first chooses his "personal" speed in 10 km/h intervals as show in Figure 6.8.

Figure 6.7: ACC Sensors Monitoring the Vehicles Ahead

Figure 6.8: ACC Lights When Approaching a Slower Car

6.3.2 ACC with Stop & Go

This system monitors the flow of traffic ahead of the vehicle, even if its forward progress is only stop-and-go. Even on everyday routes, such as driving to work, ACC enables a new kind of freedom of movement, not only allowing drivers to arrive more stress-free and in better safety, but also making driving a pleasure again despite all the hectic traffic on the roads. It's also helps fuel saving driving.

6.4 Adaptive Light Control Systems

This set of ADAS includes at the moment Adaptive High Beam Assist, Inter Urban Light Assist, Map supported Frontal Lighting, Partial High Beam Assist. A light-beam controller is used to support drivers in controlling vehicle's beams increasing its correct use, since usually drivers do not switch between high beams and low beams or vice versa when required. The adaptive light controller manages the spinning modules so that they always provide the perfect light for interurban, urban and highway driving.

In AUDI adaptive light system, a video camera mounted in front of the inside mirror identifies preceding and approaching vehicles by their lights. The system adapts the vehicle's own light through a smooth range that always provides the maximum possible brightness. , For example, in the AUDI solution the headlight control is coupled with the navigation system, which reads the route data in advance and transmits them to the light computer, so as to trigger the longer-range highway lighting while still on the on-ramp to the highway. The system automatically switches on the cornering light before entering an intersection. The high-beam assistant is available in many Audi models, which uses a small camera in the rearview mirror. It detects upcoming vehicles and towns based on their radiance and switches automatically between the high and low beams. From the interaction point of view the driver can control the function of the adaptive light in the Audi drive select.

6.5 Park Assistance System (PAS)

Parking Assist System (PAS), helps drivers in parking their vehicle via an in dash screen and button controls. The car can navigate itself into a parking space with slight input from the driver. The first solution in the market had been introduced by Toyota. In the Toyota Lexus system, the driver is accountable for checking to see if the symbolic box on the screen correctly recognizes the parking space. If the space is large enough to park, the box will be green in color; if the box is incorrectly placed, or lined in red, using the arrow buttons moves the box until it turns green. Once the parking space is correctly identified, the driver confirms and take his/her hands off the steering wheel, while keeping the foot on the brake pedal. Figure 6.9 shows the Toyota Lexus park assist function on the display in the center stack.

Figure 6.9: Lexus Backup Camera Showing the Parallel Park Setup

Moreover, switching to reverse parking automatically activates the backup camera system, and the driver decides on the reverse park guidance button on the navigation/camera touchscreen (the grid appears with green or red lines, a flag symbol representing the corner of the parking spot, and adjustment arrows; reverse parking adds rotation selection). The system is set up so that at any time the steering wheel is touched or the brake firmly pressed, the automatic parking will disengage.

The vehicle also cannot overdo a set speed, or the system will be deactivated. The driver can then shift to drive and make adjustments in the space if necessary. Usually the driver can customize the display mode and the volume and frequency of the acoustic signal in the in-dash screen. A Blinking LED on button + continuous beeping indicates a system failure.

6.6 Night Vision System (NVS)

The information on NVS partially overlaps with paragraph 6.2.1 on pedestrian detection. Anything that generates heat such as a person, an animal and to some extent trees and bushes can easily be monitored on the display. NVS makes it possible for the driver to discover an object much sooner. The system can be also found in cars like BMW, and Cadillac. Thanks to an infrared camera, mounted in the front of the car, the driver can when driving in the dark, discover a human being or an animal up to 300 meters away. While driving at the speed of 100 km/h, the driver can determine a person up to five seconds before s/he is light up by the cars headlight. The extra five seconds could potentially help the driver to increase the safety margins and decrease the stress. The image section also follows the road even in curves and objects far away can be enlarged. The NVS can be accomplished in different forms, such as infrared headlamps and thermal imaging cameras. Most common way out is the infrared.

As mentioned in 6.2.1, during night if a pedestrian enter in the car’s path, drivers receive an audible and visual acute warning in the instrument cluster (e.g. in BMW and Mercedes systems) and, if the danger is imminent, it an alarm and pre-charges the car's brakes. Different solutions in relation to HMI of night vision system have encompassed for instance head-up displays3. For example, the System introduced on Toyota Lexus LS6004. Rather than a small display screen in the instruments cluster, the Night Vision picture is directly projected on the windscreen. This helps reduce the head movements for the driver and thus gives less distraction. A potential problem in the future could be with camera assisted night vision that notifies the driver of what is approaching on the road. If the driver focuses too much on the display with night vision, he might fail to see things on the road not displayed on the screen. Figure 6.10 shows the NVS heads-up display (HUD) indication introduced in the Toyota Lexus LS600.

Figure 6.10: NVS HUD Introduced on Toyota Lexus LS600

6.7 Traffic Sign and Traffic Light Recognition Systems

6.7.1 Traffic Sign Recognition System (TSRS)

As we know, a failure to see a road sign displaying the permissible maximum speed can be expensive and, especially for people who rely on their driving license for their work, the consequences can be unpleasant. Traffic Sign Recognition System (TSRS) has a display on the instrument panel to remind drivers of the current speed limit. TSRs enables the vehicle to identify the traffic signs placed on the road e.g. "speed limit" or "children" or "turn ahead" and the traffic light. The technology is being developed by many automotive suppliers, including Continental and Delphi. Second generation systems can also detect overtaking restrictions. One such system was introduced in 2008 in the Opel Insignia. Currently, this system is also available in the Volkswagen Phaeton and in several Volvo models. This is achieved through multiple use of the same camera which is also used for the Lane Departure Warning system. When combined with high-performance software, it can also recognize speed limit signs. Digitized speed limit information of the on board navigation system will be incorporated to be prepared for roads not assigned with speed limit signs. Figure 6.11 shows the Traffic sign/light recognition system.

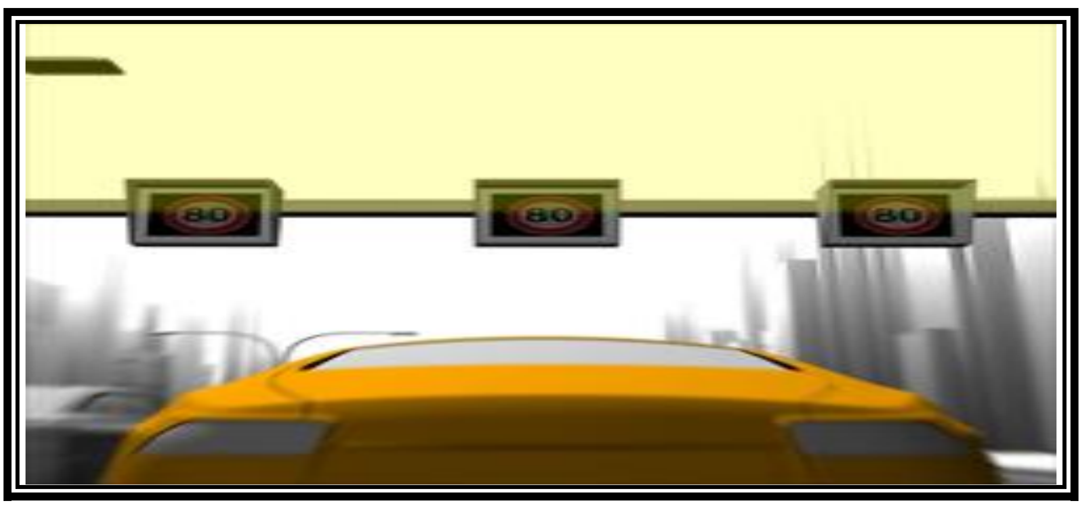


Figure 6.11: Traffic Sign/Light Recognition

6.7.2 Traffic Light Recognition System (TLRS)

Traffic Light Recognition System are under a large scale test in Japan undertaken by Toyota. The system pass on the traffic light information to vehicle, providing alerts to the vehicle occupants via the audio system and on-screen on the navigation system. Similar drivers' warning solutions applies to traffic sign detection. For instance the BMW traffic sign recognition system6 depicts overtaking ban or speed limit on the instrument panel in the form of a traffic sign until the restrictions is changed or lifted. In the Mercedes S class 2014 solution a visual and acoustic warning is additionally output in the instrument cluster.

6.8 Navigation and Map Supported Systems

Navigation and Map Supported Systems include for example Curve Warning System and Fuel Economy System. The Curve Speed Warning System is designed to avoid drivers from entering a curve at a speed faster than the speed permissible at the impending part of the route. Also, it provides the speed limit cautions based on the road side signs. Its integration with navigation maps permits prognostic ability of the system in relation to road curvature data. On every occasion the driver go beyond this critical speed, a warning is give out. In case of the fuel economy system, Road slope, traffic sign and signal location derived from the digital map enable predictive energy used. Also, the driver information is delivered through the Navigation screen. In this kind of systems drivers have also the options to choose e.g. fastest route or eco-route, and can monitor and track their vehicle's real-time fuel economy.

6.9 Vehicle Interior Observation and Driver Monitoring Systems

These systems include driver impairment warning system (e.g. drowsiness, fatigue), driver visual distraction warning system (e.g. focus on the driving task, eye gaze evaluation), occupant detection system. The driver monitoring systems are explicitly aimed at identifying signs of driver fatigue. Instead of activating only when a vehicle is in danger of drifting from its lane, these systems look for the sort of unpredictable movement naturally associated with an impaired driver. Moreover, the other systems take it a step further by observing the driver's eyes and face for signs of drowsiness. Each OEM that offers a driver alert system has its own take on the technology, but the most common configuration uses a front-facing video camera that is mounted so that it can track both the left and right hand lane markings. Some of these systems can also function if only one lane marking is visible. By tracking the lane markings, or examining other inputs, the driver alert system can detect signs of fatigued driving. Some driver alert systems use complex algorithms to differentiate between intentional movements and the sort of drifting and jerky steering typically associated with a fatigued driver. Other systems have sensitivity controls that the driver can adjust, and most can be switched of manually. In addition to monitoring the way that a car is being driven, some driver alert systems can also monitor the driver by looking for signs of drooping eyelids, slackened facial muscles, or other tell-tale signs of drowsiness. These features aren't as widely available, though a number of OEMs are working with advanced facial recognition technology for the future implementations of their driver alert systems.

In special cases, when a driver monitoring system detects signs of driver fatigue or drowsiness, a number of things can happen. Some of these systems provide a multi-tiered method, which increases in the severity as time passes. These systems will typically start off by sounding some type of buzzer or chime and illuminating a light on the dash. If the driver stops driving erratically at that point, the system will typically shut off the nag light and reset itself. However, if the signs of fatigued driving continue, the driver alert system may sound a louder alarm that requires some sort of driver interaction to cancel. Some driver alert systems eventually progress to an alarm that can only be cancelled by pulling the vehicle over and either opening the driver's door or shutting the engine off.

Some of the OEMs that offer some type of driver alert system include: Ford Driver Alert, Mercedes-Benz Attention Assist, Toyota Driver Monitoring System, Volkswagen Fatigue Detection System, and Volvo Driver Alert.

6.10 Autonomous Driving

Its notion that autonomous car means fully self-controlled and openly running on road without a driver. But to have that level of automation is not possible anywhere in near future. As we saw the road map to fully automated driving, there are a lot of challenges regarding safety and security. The proper infrastructure is not ready for it, like V2V and V2I (infrastructure) communication. According to NHTSA guidelines vehicle automation as having five levels:

- No-Automation (Level 0): The driver is in complete and sole control of the primary vehicle controls – brake, steering, throttle, and motive power – at all times.
- Function-specific Automation (Level 1): Automation at this level involves one or more specific control functions. Examples include electronic stability control or pre-charged brakes, where the vehicle automatically assists with braking to enable the driver to regain control of the vehicle or stop faster than possible by acting alone.
- Combined Function Automation (Level 2): This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions. An example of combined functions enabling a Level 2 system is adaptive cruise control in a combination with lane keeping.

- Limited Self-Driving Automation (Level 3): Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for the changes in those conditions requiring transition back to driver control. The driver is expected to be available for an occasional control, but with sufficiently comfortable transition time. The Google car is an example of limited self-driving automation.
- Full Self-Driving Automation (Level 4): The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for the control at any time during the trip. This includes both occupied and unoccupied vehicles. Though regulations don't allow to have fully automated vehicles on road, level 2 to level 4 of autonomous vehicle are already on the road. Some of the autonomous technology is listed below, which are similar to ADAS in context to assisting the driver in different modes.

6.10.1 Low Speed Companion

Traffic jams are physically strenuous, strain the driver's nerves, and carry an elevated risk of rear-end collisions – a prime application for automated driving. The driver can simply push a button to delegate all of this stress to the vehicle. Braking, starting, and adherence to a safe following distance take place automatically, leaving the driver free to enjoy his or her favorite music, talk on the phone, or chat with passengers. Through connectivity with the infrastructure, the vehicle even recognizes when the traffic jam comes to an end, reliably turning these functions back over to the driver.

6.10.2 Parking Companion

The Parking Companion feature lets any driver easily conquer any parking space. Once the assistant function is activated, the vehicle automatically scans parking areas for a suitable space while passing by and then offers that space to the driver. If the driver accepts the suggestion, the vehicle takes care of the rest: steering, controlled acceleration and braking right up to the final parking position.

6.10.3 Parking Pilot

As vehicles become more and more interconnected with the surrounding infrastructure, driverless parking will also become a possibility in the future. In this process, the vehicle is operated via a special smartphone app, for example. The driver initiates the parking process after leaving the vehicle. The vehicle connects with the infrastructure – such as the parking lot – and drives to an assigned parking space completely automatically. When the driver wishes to move on, the vehicle is then called back up using the smartphone.

6.10.4 Highway Chauffeur

Long drives on the highway as a way of gaining extra time? Automated driving makes exactly that possible. If the driver has activated the highway chauffeur feature, for example, he or she can use that time to talk on the phone, check e-mail, or just relax and enjoy entertainment provided by the multimedia system. The vehicle handles all of the management-related tasks, securely overtaking slower vehicles and even conquering complex situations, such as changing highways, driving in tunnels, and toll booths. The driver does not have to take over again until exiting the highway – which the vehicle announces ahead of time.

6.10.5 Highway Pilot

The highway pilot feature makes a car an unbeatable option for an individual travel. It not only masters all of the functions that the highway chauffeur offers; it also has an additional level of safety that lets the driver turn his or her attention away from traffic completely, for a longer period. The vehicle handles all of the management-related tasks, plus it initiates the process of returning responsibility for these functions to the driver well in advance. In any emergency situation that may occur, the vehicle will be able to automatically pull over to the shoulder and place an emergency call to ask for help.

CHAPTER 5

7. EXPERIMENT AND DATA ANALYSIS

In this chapter, we conducted an experiment to measure the driver distraction in the form of reaction time. It explains the methodology used to measure the distraction, experiment execution, data and statistical analysis. At the end of this chapter the results of the experiment have been discussed.

7.1 Experiment Description

In April 2013, NHTSA released voluntary guidelines for the manufacturers, recommending that in-car systems have to be designed such that divers do not take their eyes off the road for more than 2 seconds per interaction or a touch, 12 seconds in total per task or a total of six touches. For this experiment, the abstract layouts of varying numbers of icons on varying sizes of screens have been tested to effectively calculate driver distraction. The goal was to benchmark an abstract screen layout of in-car user interface (UI), to measure the effects of screen size and number of icons on driver distraction and to evaluate the effects of our minimalist design on driver distraction. The experiment used two different sizes of android tablets as UIs. The following conventions have been used throughout the experiment:

1) Small Screen: - An android tablet with a 7” (inch) screen is known as “small screen”. Small screen has two layouts of icons; first with 24 icons and second with 8 icons.
2) Large Screen: - An android tablet with a 10” inch screen is known as ‘Large screen”. Large Screen has two layouts of icons; first with 24 icons and second with 8 icons.
3) Reaction time (in seconds): - We measure this metric manually and the unit of measurement is in seconds. All four UI’s were tested for the driver

distraction, and the distraction is measured in terms of reaction time. The reaction time is considered as the amount of time a driver takes his/her eyes off the road while driving to interact with the screen in the center-stack. The Driver is asked to click a certain numbered icon on the screen in the center-stack while driving under the normal conditions. The time taken to click the numbered icon is noted as the reaction time. The greater the reaction time, the higher the distraction. Also, any deviation in those readings without other modifications in the experiment should indicate distraction occurrence. This step is repeated 5 times for each UI screen, and a total of 20 readings are taken per participant, 5 readings per each UI Screen.

The HyperDrive Simulator was used for this particular experiment, and it is an important part of this project. The images below show the placement of the four different UI's of our application in their actual setup inside the simulator dashboard. Figures 7.1, 7.2, 7.3, and 7.5 show the experiment setup with each UI.

Figure 7.1: Small Screen UI with 24 Icons

Figure 7.2: Small Screen UI with 8 Icons

Figure 7.3: Large Screen UI with 24 Icons

Figure 7.4: Large Screen UI with 8 Icons

7.2 Hypothesis

For the design and development of least distractive in-car UI, it is necessary to know what is an acceptable distraction caused by the UI. It was revealed that most of the cars analyzed in this report contained more than 30 input buttons at a time, including hard and soft buttons together (e.g., physical buttons, manual knobs, icons, menus).For that reason, the developed user interface has an abstract layout of icons of varying sizes, and an emphasis has been given to the number of icons.

Standard statistical procedure involves the development of a null hypothesis, a general statement or default position that there is no relationship between two quantities. Rejecting or disproving the null hypothesis is a central task in the modern practice of science, and gives a precise sense in which a claim is capable of being proven false. What statisticians call an alternative hypothesis is simply a hypothesis that contradicts the null hypothesis.

Our Null hypothesis: UI with the large screen is better than UI with the small screen.

Our Alternate hypothesis: A minimalist UI design with small screen having fewer icons (8 icons) is better than the UI with large screen having more icons (24 icons).

Our secondary hypothesis:

1. There is no difference in interaction between the UIs with 8 icons and 24 icons.
2. There is a significant difference in interaction between the UIs with small screen and larger screen size.

7.3 Experiment Execution Details

Test Cases:

A combination of the dimensions, mentioned in the previous section, were tested in the driving environment with four different UIs (four different test cases) as follows:

1. Small screen size , 24 icons
2. Small screen size , 8 icons
3. Large screen size, 24 icons
4. Large screen size, 8 icons

The HyperDrive Simulator was used for this experiment. More details are mentioned in the Appendix B. The volunteers were asked to drive on a previously programmed route, with possible driving tasks like left turns at a signal, pedestrians crossing, curved road and following a car. Figure 7.5 shows the overview of the programmed route for the experiment.

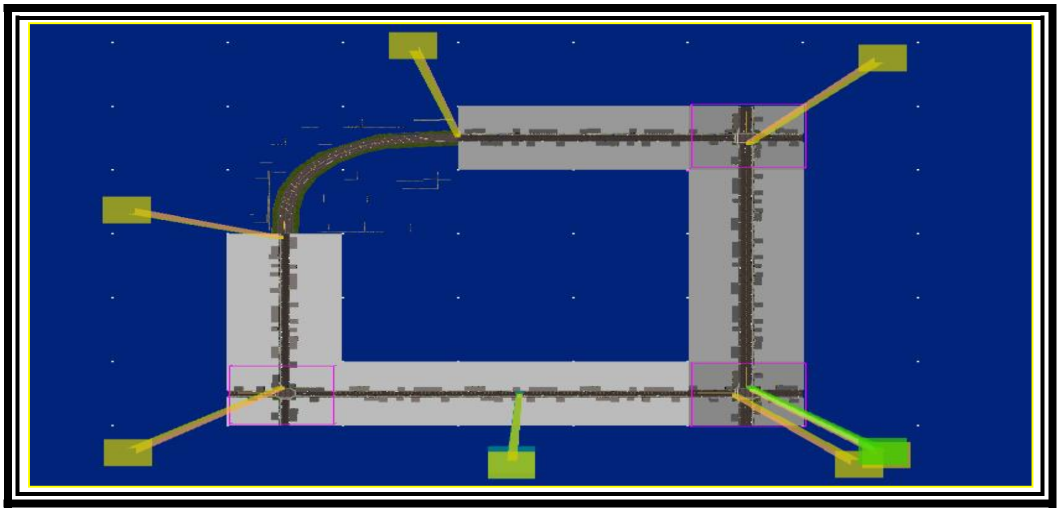


Figure 7.5: The Route Overview

The volunteers were asked to maintain a speed between 40–50mph (for the better analysis of results), stay within the lane when they are not distracted, follow any preceding car without overtaking and follow all traffic rules. At the starting point, the volunteers would start from the lane to the right of the centerline. Each volunteer was given a free drive to get acquainted to the driving environment on the programmed route without any distractions. The drive was divided in two parts with a total of four different UI test cases. The first half of the drive was tested with small screen size UI and two cases: 24 icons and 8 icons. The second half of the drive was tested with large screen size UI and two use cases: 24 icons and 8 icons. Both the drives were monitored closely. The volunteers' reaction time (from the time that the number is mentioned till the driver clicks the number) was also noted. For each UI, the driver was asked to click a specific icon 5 times. Figure 7.6 shows the starting point of the drive.

Figure 7.6: Rout Starting Point

The first complex driving task was taking a left turn. The driver would have to stop at the intersection and wait for the green light and then make a turn while following another car also making the same turn. There were other cars at the intersection, all following traffic rules.

Figure 7.7: Left Turn

The curved drive on the road without getting distracted is the 2nd complex driving task. At the start of this path, the preceding vehicle was taken out and another car joined the roadway.

Figure 7.8: Curved Road

Following a car is the 3rd task. The driver had to stay behind and follow the red car. On the next left turn the driver had to follow the route and the red car would go straight.

Figure 7.9: Follow a Car

Pedestrian jaywalking is the last task. Here, to measure reaction time more effectively, we have pedestrians crossing the road at unexpected times. The driver then proceeds forward and reaches the goal.

Figure 7.10: Pedestrian Crossing

7.4 Data Analysis

In this particular experiment, a total of 20 volunteers took part. No personal information was collected about the participants. There were 2 types of data obtained – Driver Reaction Time and Driving Simulation Metrics. The reaction times were closely monitored and noted manually using a stopwatch, and excel spreadsheet was used to note the readings. Driving Simulator Metrics were used to perform statistical analysis of the collected data. The order of UI's tested during the experiment was same as the order of the figures above from Figure 7.1 – 7.4. The data analysis was done mainly taking the Mean reaction time per person. It was categorized in major 4 groups as given below.

1) Mean reaction time for 24 icons in small screen and Mean reaction time for 24 icons in large screen. Table 7.1 shows the comparison of both the screens for 24 icons' layout.

Table 7.1: Mean Reaction Time for 24 Icons layouts

#Participant (P)	**Mean Reaction Time (Seconds) for 24 Icons in Small Screen (7")**	**Mean Reaction Time (Seconds) for 24 Icons in Large Screen (10")**
P1	1.788	1.698
P2	1.724	1.972
P3	1.474	1.716
P4	1.944	2.038
P5	1.814	1.846
P6	2.12	2.484
P7	1.908	1.884
P8	1.706	2.370
P9	2.575	2.374
P10	2.324	1.842
P11	1.494	1.742
P12	1.648	2.066
P13	1.676	1.822
P14	2.220	1.968
P15	1.852	1.832
P16	1.730	2.100
P17	1.430	1.678

P18	2.302	2.012
P19	1.974	2.008
P20	1.932	2.052
Total Mean Reaction Time (Seconds)	**1.882**	**1.994**

2) Mean reaction time for 8 icons in small screen and Mean reaction time for 8 icons in large screen. Table 7.2 shows the comparison of both the screens for 8 icons' layout.

Table 7.2: Mean Reaction Time for 8 Icons Layouts

#Participant (P)	**Mean Reaction Time (Seconds) for 8 Icons in Small Screen (7")**	**Mean Reaction Time (Seconds) for 8 Icons in Large Screen (10")**
P1	1.060	1.050
P2	1.196	1.104
P3	1.136	1.178
P4	1.020	1.196
P5	1.276	0.910
P6	1.094	1.168
P7	1.160	1.138
P8	1.338	1.100
P9	1..092	1.030
P10	1.382	1.150

P11	0.894	1.044
P12	0.964	1.076
P13	1.032	0.928
P14	1.022	1.040
P15	1.074	1.002
P16	1.064	1.140
P17	0.898	0.860
P18	1.230	1.066
P19	1.086	1.036
P20	1.040	1.054
Total Mean Reaction Time (Seconds)	**1.103**	**1.068**

3) Mean reaction time for the small screen (included reaction time for the both layouts in small screen: 24 icons and 8 icons) and Mean reaction time for the large screen (included reaction time for the both layouts large screen: 24 icons and 8 icons). Table 7.3 shows the comparison of the small screen and the large screen for the layouts.

Table 7.3: Mean Reaction Time for Small and Large Screens

#Participant (P)	**Ave Reaction Time (Seconds) for the Small Screen (7”)**	**Ave Reaction Time (Seconds) for the Large Screen (10”)**
P1	1.424	1.374

P2	1.460	1.538
P3	1.305	1.447
P4	1.482	1.617
P5	1.547	1.378
P6	1.607	2.008
P7	1.534	1.511
P8	1.522	1.735
P9	1.833	1.702
P10	1.853	1.496
P11	1.195	1.393
P12	1.308	1.621
P13	1.354	1.375
P14	1.621	1.513
P15	1.463	1.417
P16	1.397	1.620
P17	1.164	1.269
P18	1.766	1.539
P19	1.530	1.522
P20	1.486	1.552
Total Ave Reaction Time (Seconds)	**1.493**	**1.531**

4) Mean reaction time for the UI with 24 icons (included reaction time for 24 icons' layout in both screens: small screen and large screen) and Mean reaction time for the UI with 8 icons (included reaction time for 8 icons' layout in both screens: small screen and large screen). Table 7.4 shows the comparison of 24 icons and 8 icons for both the screen sizes. In Table 7.4 we can see, for many participants (P6, P8, P10, P14, P18) the mean reaction time for the UI with 24 Icons is noted to be higher than (more than 2 sec) the acceptable reaction time according to NHTSA guidelines. Even, the total Mean reaction time for 24 icons is very close to the lime of 2 sec.

Table 7.4: Mean Reaction Time for 24 Icons and 8 Icons

#Participant (P)	Mean Reaction Time (Seconds) for the UI with 24 Icons	Mean Reaction Time (Seconds) for the UI with 8 Icons
P1	1.73	1.055
P2	1.848	1.150
P3	1.595	1.157
P4	1.991	1.108
P5	1.832	1.093
P6	2.484	1.131
P7	1.896	1.149
P8	2.038	1.219
P9	2.47	1.061
P10	2.083	1.266

P11	1.618	0.969
P12	1.857	1.072
P13	1.749	0.980
P14	2.103	1.031
P15	1.842	1.038
P16	1.915	1.102
P17	1.554	0.879
P18	2.157	1.148
P19	1.991	1.061
P20	1.992	1.047
Total Mean Reaction Time (Seconds)	**1.938**	**1.086**

7.5 Statistical Analysis (SA)

Statistics is the study of the collection, analysis, interpretation, presentation, and organization of data. Statistics deals with all aspects of data including the planning of data collection in terms of the design of surveys and experiments. Two main statistical methodologies are used in data analysis: descriptive statistics, which summarizes data from the sample using indexes, such as the mean or standard deviation, and inferential statistics, which draws conclusions from data that are subject to random variation (e.g., observational errors, sampling variation). Statistical analysis is fundamental to all experiments that use statistics as a research methodology. Further, statistical analysis can be broken down into five discrete steps, as follows:

- Describe the nature of the data to be analyzed:- In this experiment, the data collected about the reaction time is subjective to the complexity of the UI
- Explore the relation of the data to the underlying population: - In this experiment, the reaction time for the different UIs may differ based on the simplicity or the complexity of the UI design.
- Create a model to summarize understanding of how the data relates to the underlying population:- For this experiment, four different test cases were developed as described in section 7.3 to check the null hypothesis, alternate hypothesis, and secondary hypothesis.
- Prove (or disprove) the validity of the model.

Calculation of the test statistic requires four components:

- The Mean of the sample (observed Mean):- In this experiment, it is the total mean reaction time which has been calculated in section 7.4 for each test case.
- The population Mean (expected mean or hypothetical mean):- According to NHTSA guidelines the reaction time for a single interaction must be less than 2 seconds, which means the ideally expected values of reaction time must be in the range of 0-2 seconds. This condition gives the hypothetical mean (population mean) for the experiment as 1 second.

- The standard deviation (SD) of the sample Mean: - In this experiment there were a total of 20 participants, and the mean reaction time has been calculated in section 7.4 followed by the calculation of the SD for each test case.
- The number of observations (N):- Sample size in the experiment (for each test case , number of reading taken during the experiment is100)

With these four pieces of information, we calculated the following statistics:

$$t = \frac{\text{(observed-expected)}}{SD_{observed} \times \sqrt{\text{(number of observations in sample / number of observations-1)}}}$$

In this experiment, we have observed the mean reaction time using small screen and large screen. Observing different sample means is not enough to persuade us to conclude that the populations have different means. It is possible that the populations have the same mean (i.e., the size of the screens have no effect on the reaction we are measuring) and that the difference we observed between sample means occurred only by chance. There is no way we can ever be sure if the difference we observed reflects a true difference or if it simply occurred in the course of random sampling. All we can do is calculate probabilities. The P value is a probability, with a value ranging from zero to one. The confidence interval (CI) of a mean tells us how precisely we have determined the mean. In statistics, the number of degrees of freedom (df) is the number of values in the final calculation of a statistic that are free to vary. For example, we measure weight in a small sample (N=5), and compute the mean. That mean is very unlikely to equal the population mean. The size of the likely discrepancy depends on the size and variability of the sample.

An unpaired sample t-test is used to compare two different mean of two unpaired samples of scores to a hypothetical mean (in this experiment 1). H_0: $M - \mu = 0$, where M is the sample mean and μ (=1) is the population or hypothesized mean. As above, the null hypothesis is that there is no difference between the sample means and the known or hypothesized population mean.

Mathematical Equation:-

$$t = \frac{M - \mu}{\sqrt{\frac{\Sigma X^2 - ((\Sigma X^2)/N)}{(N - 1)(N)}}}$$

If our sample is small and variable, the sample mean is likely to be quite far from the population mean. If our sample is large and has little scatter, the sample mean will probably be very close to the population mean. Statistical calculations combine sample size and variability (standard deviation) to generate a CI for the population mean. As its name suggests, the CI is a range of values. To interpret the confidence interval of the mean, we must assume that all the values were independently and randomly sampled from a population whose values are distributed according to a Gaussian distribution. If we accept these assumptions, there is a 95% chance that the 95% CI contains the true population mean. In other words, if we generate many 95% CIs from many samples, we can expect the 95% CI to include the true population mean in 95% of the cases, and not to include the population mean value in the other 5%. The standard error of the mean (SEM) quantifies the precision of the mean. It is a measure of how far the sample mean is likely to be from the true population mean. It is expressed in the same units as the data.

The unpaired t test compares the means of two unmatched groups, assuming that the values follow a Gaussian distribution. The unpaired t test assumes that the two populations have the same variances (and thus the same standard deviation). Following are the Statistical analysis results using the above terms and methodology.

1) 24 icons in the small screen Vs 24 icons in the large screen

   Unpaired t-test results:-

Table 7.5: SA for 24 Icons in Small and Large Screen

Group	24 Icons in Small Screen	24 Icons in Large Screen
Mean	1.881930000	1.994300000
SD	0.435210000	0.498892500
SEM	0.04352190	0.04989250
N	100	100

P = 0.0912

Statistical significance: - By conventional criteria, **this difference is considered to be not quite statistically significant.**

Confidence interval (CI) = 0.112370000

95% CI of this difference: From -0.242926175 to 0.018186175

Intermediate values used in calculations:

t = 1.6973

df (degree of freedom) = 198

Standard error of difference = 0.066

2) 8 Icons for the Small Screen Vs 8 Icons for the Large Screen

Unpaired t test results:-

Table 7.6: SA for 8 Icons in Small and Large Screen

Group	8 Icons for the Small Screen	8 Icons for the Large Screen
Mean	1.0131000	1.0685000
SD	0.1885800	0.1769400
SEM	0.01885820	0.01769480
N	100	100

P = 0.0334

Statistical significance: - By conventional criteria, **this difference is considered to be not statistically significant.**

Confidence interval (CI) = 0.03460000

95% CI of this difference: From -0.01639632 to 0.08559632

Intermediate values used in calculations:

t = 1.3380

df (degree of freedom) = 198

Standard error of difference = 0.026

3) Small Screen Vs Large Screen

Unpaired t test results-

Table 7.7: SA for the Small and the Large Screen

Group	For the Small Screen	For the Large Screen
Mean	1.4925000	1.5314000
SD	0.5139300	0.5953100
SEM	0.0363403	0.0420948
N	200	200

P = 0.4846

Statistical significance: - By conventional criteria, **this difference is considered to be not statistically significant.**

Confidence interval (CI) = -0.0389000

95% CI of this difference: From -0.1482282 to 0.0704282

Intermediate values used in calculations:

t = 0.6995

df (degree of freedom) = 398

Standard error of difference = 0.056

4) 24 Icons vs 8 Icons

Unpaired t test results-

Table 7.8: SA for 24 Icons and 8 Icons

Group	24 Icons	8 Icons
Mean	1.9381200	1.0858000
SD	0.4715200	0.1836700
SEM	0.0333415	0.0129874
N	200	200

P < 0.0001

Statistical significance: - By conventional criteria, **this difference is considered to be extremely statistically significant.**

Confidence interval (CI) = 0.8523200

95% CI of this difference: From 0.7819753 to 0.9226647

Intermediate values used in calculations:

t = 23.8200

df (degree of freedom) = 398

Standard error of difference = 0.036

7.6 Results

The graph shown in Figure 7.11 below presents all the data collected during the experiment. It shows that for each person the Reaction time can very significantly, depending on the no of icons and the size of the UI screen.

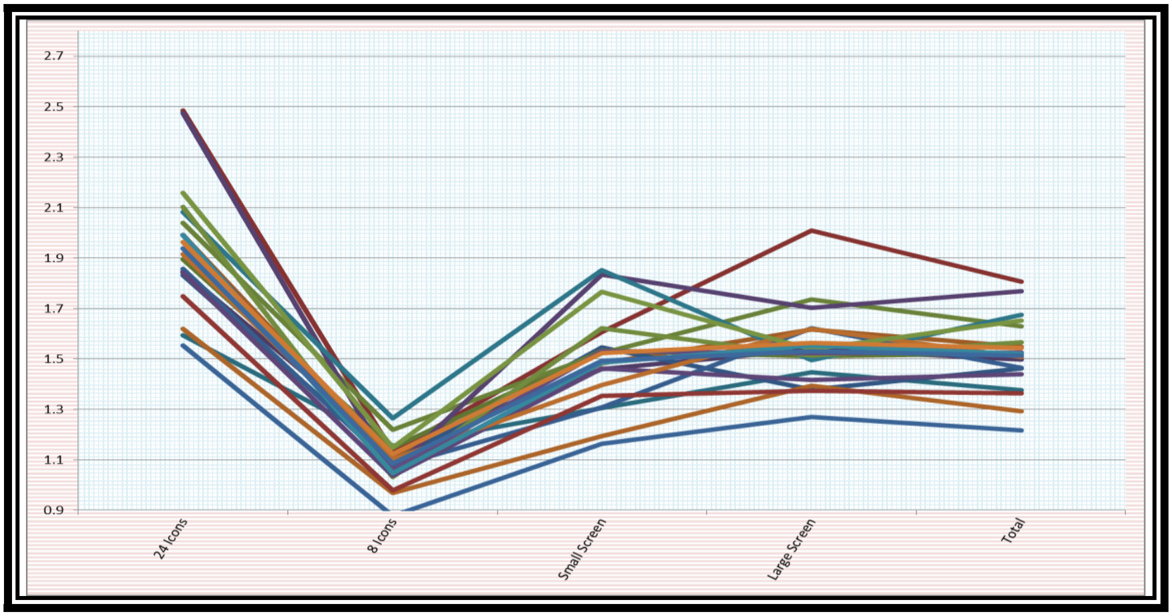


Figure 7.11: Reaction Time Per-participant

- The data collected from the experiment, shows that for the more number of icons (24 icons), the large screen is worse than the small screen and it required more attention, which disproves our null hypothesis that the larger screen is better and less distractive than the smaller screen. SA results also confirms the experiment data.

- The results from SA indicated that for the fewer number of icons (8 icons), there is no statically significant difference between the small screen and the large screen, which again disproves the secondary hypothesis: “there is a significant difference in interaction between the small screen and the large screen”.
- The data from SA and the Table 7.3 showed that there is no statistically significant difference in the UI with small screen and the large screen, which is opposite to our null hypothesis.
- The data shows that our minimalist design with 8 icons was well within the NHTSA’s criteria. Total Mean reaction time 1.086 seconds, which nearly the half of the NHTSA’s criteria. This disproves our secondary hypothesis, with a mean distractive task time as low as 0.876 seconds per screen to as high as 1.266 seconds.
- The SA showed there is an extremely statistically significant difference in the UI with 24 icons and UI with 8 Icons. The mean reaction time for the UI with 24 icons is 1.938120 seconds, which can significantly differ by 0.852 seconds and might cross the limit of 2 seconds. Hence, the UI with 24 icons doesn’t meet requirement of NHTSA’s guidelines.

CHAPTER 8

8. SUMMARY AND FUTURE WORK

This chapter summarizes the analysis results, lists the identified trends in the smart car technology, provides the directions to the future work in the area, and concludes the thesis.

8.1 Summary of Analysis in HCaI

The Analysis results are summarized as follows:

- Starting with in-car dash analysis, the result indicates that around 80 percent of the new cars come with an inbuilt infotainment system, which included digital touch display overloaded with lots of information about various functionalities and full of unnecessary small icons, texts and numbers in the center-stack. The installation position of the touch display varied based on the category of the car either lower, middle or higher placed in the center stack. For example, 1) In the sports cars, lower paced touch display inclined towards the driver; 2) In the economy and premium cars, 6-8 inch small touch display, placed in the middle of center stack; and 3) In the luxury cars, higher placed 8-10 inch touch display in center stack
- Almost around 60 percent of cars provided the small digital display in the instrument cluster, especially around 95 percent of new premium and luxury cars provided the quick access of infotainment functionalities in the instrument cluster, making it convenient though more crowded.
- Around 70 percent of the new cars provided a steering wheel with more than 8 shortcut buttons on it. The number of buttons were increased due to increased number of functionalities and shortcuts to control them.

- Nearly 55 percent of the new cars were observed to have a cluttered center-stack design including so many very small, manual buttons with improper use of the space. These center -stack designs lacked proper groupings of the functionalities.
- The voice recognition system is the second most adopted technology in the new cars analyzed in the study. In those cars, 75 percent of new cars were observed to have varied levels of inbuilt voice recognition system – 1) less accurate VR with flexible commands but requires training, and 2) VR with good accuracy but very limited commands. Research showed that the voice recognition system, which is supposedly less distracting can also cause dangerous distraction while handling some particular features, such as editing voice mail or messages, entering map addresses using voice input or taking notes.
- ADAS technology is the third feature, a center of attraction in the new car. Around 78 percent of the new cars observed contained some common ADAS features, such as ACC, ABS, lane departure assist, and parking assist. On the other hand, almost all the cars in the luxury car segment comes with inbuilt ADAS.
- The ADAS technology can help reduce the driver workload by assisting the driver in handling some of the car functionality and alerting the driver to avoid accident in a timely manner. In some emergency cases, the ADAS can even take over control of the car and perform the required action to avoid any dangerous consequences.
- With the physical evolution of in car user interfaces, the complexity of interaction inside the car has also increased, which results in an increase in the cognitive load and the driver distraction.
- With the increased number of cars on the road and the increased use of information systems in the vehicle, the driver distraction becomes a very serious problem around the world.

- The ADAS and the speech recognition is considered as the technologies which could help reduce the problems related to distracted driving and the cognitive load.
- It was realized that no natural language is possible for the in-car environment anywhere in near the future, thereby the system is not perfect.
- The research shows that the driver distraction is a costly problem, both in terms of life and money.
- Driver distraction is not easy to solve as there are a lot of challenges regarding how to quantify the distraction while driving.

8.2 Trends Identified

The HCI technology is growing on all fronts, such as computing, sensing, and virtual reality with a great pace and they are extending to the functionalities of a car. To name a few, such as high definition graphics processing units (GPUs), high performance and multi-core processors, high resolution video and image processing techniques, high definition cameras, long range and short range high precision radars, LIDAR's, ultrasonic radars, multi-touch digital displays, speech recognition systems, haptic and sensing technology, augmented reality, and virtual key board and display (such as heads-up display- HUD). From the overall analysis, the following trends are identified:

- First, from the analysis of today's cars, it is evident that the smart cars are becoming more digital. From a traditional instrument cluster (analog) to a partially digital touch display, and from a plethora of small manual buttons in the center-stack to a touch display with icons and menus, and better user interaction.
- Moreover, from the analysis of future concept cars, it was observed that even the current center stack design, which is a mix of manual buttons and digital touch display, is getting replaced completely by a big digital touch display with high definition graphics.

- The instrument cluster in the cars today, which is a combination of analog gauges and small digital display, is getting replaced completely by a digital touch display. Even in some concept cars, the infotainment display and instrument cluster are combined in a big display, making the best use of the space.
- Heads- Up Display (HUD) has started appearing more frequently and it could be also considered as one of the good features on the car that could help minimize driver distraction.
- In the near future, we could see higher function prosthetics, brain computer interfaces with better controls, supporting technology to improve speech recognition and camera gesture recognition, gaze detection, haptic controls, and augmented reality being used more.

8.3 Future Work

From the analysis, it was revealed that most of the in-car user interfaces are overcrowded; the center-stack alone has more than 30 input buttons (including hard and soft buttons) at a time. The experiment in this thesis confirmed that a single interaction with the UI, having 24 soft input buttons in the center stack alone, is distracting a driver on an average of 1.93 seconds. The next step could be testing the reaction time or distraction caused while interacting with a combination of hard and soft buttons. This also indicates that there is a need to redefine the framework to design the in-car user interfaces. Interaction design in the HCaI is also a big problem; some kind of tool or better guidelines are required to detect potential design flaws, which could impact the driving performance and driver cognitive load. More indicators of driver’s performance are need to be addressed, such as cognitive distraction, visual attention measure (like eye tacking), stress and frustration level measures (like physiological data), which could help in better understanding driver distraction. The flexible MMIS would be well suited for assisting drivers in self managing their cognitive load and improving overall performance by reducing unnecessary distractions as the complexity of field tasks and related communications increase. On the other hand, there is a need to import the cognitive model and interaction design methodologies from HCI to the HCaI. These methodologies are great proven tools, which could help design a better user interaction, such as the following:

- Task modeling: - Task models are very useful when designing and developing interactive systems. They describe the most logical activities that have to be carried out in order to reach the user's goals considering all the aspects of UI design, such as usability, learnability, and especially safety in context to automotive applications.
- Use cases and scenario: - Use cases are important requirement techniques that have been used in software engineering since 1992. Use cases add value because they help explain how the system should behave and in the process, they also help brainstorm what could go wrong. They provide a list of goals and this list can be used to establish the cost and complexity of the system.
- Mental modeling: - Mental models are psychological representations of real, hypothetical, or imaginary situations. They were first postulated by the American philosopher Charles Sanders Peirce in 1896. They play a major role in cognition, reasoning and decision-making and cognitive scientists have argued that the mind constructs mental models as a result of perception, imagination and knowledge, and the comprehension of discourse. This could really help design better user interaction considering cognitive load and driver distraction models in combination.

8.4 Conclusion

We have seen an increased number of features in vehicles and also the user interaction in–car has become overcrowded and more complex. As a result, driver distraction is growing and the number of accidents due to distracted driving is also increasing. The driver distraction in the smart car cockpit and other nomadic devices could grow even more in the future with more technology. Providing one more feature in the car might increase comfort and convenience but it can even lead to dangerous safety concerns if proper use cases and scenarios are not tested for the kind of distraction it can cause. The current state of technology is focused on the features oriented design and the sales driven approach. The in-car voice recognition is anticipated to be the solution to minimize the physical distraction, but there are a few challenges and limitations with respect to in-car environment and cognitive load. Most of the automotive manufacturers are focusing on making speech-recognition better, but it is not perfect. This faulty voice recognition system can even lead to unnoticed and more dangerous distraction if proper care is not taken while designing new interfaces with the voice interaction. MMIS and ADAS with focus on user-centered design could help improve interaction while minimizing the distraction. Lastly, in order to compete with the market we cannot reduce the basic features that are provided by all the other competitors but we can try to make driving a bit safer by improving the in-car user interaction.

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APENDIX A

CONSENT FORM

Title of Investigation: Smart Car Technologies: A Comprehensive Study of the State of the Art with Analysis and Trends

This document is to certify that I, ____, hereby freely agree to participate as a volunteer in a (research study, experiment, program, etc.) as an authorized part of the educational and research program of the Arizona State University under the supervision of Paresh Nakrani.

- The research project has been fully explained to me by Paresh, and I understand this explanation, including what I will be asked to do. A copy of the procedures of this investigation and a description of any risks, discomforts and benefits associated with my participation has been provided and discussed in detail with me.

- I have been given an opportunity to ask questions, and all such questions and inquiries have been answered to my satisfaction.

- I understand that I am free to decline to answer any specific items or questions in interviews or questionnaires.

- I understand that all data will remain confidential with regard to my identity.

- I understand that participation in this research project is voluntary and not a requirement or a condition for being the recipient of benefits or services from the Arizona State University or any other organization sponsoring the research project.

- I understand that the approximate length of time required for the participation in this research project is (15 minutes).

- I understand that if I have any questions concerning the purposes or the procedures associated with this research project, I may email to pnakrani@asu.edu

  I understand that it will not be necessary to reveal my name in order to obtain additional information about this research project from the principal investigator(s).

- I understand that if I have any questions or concerns about the treatment of human subjects in this study, I may email to pnakrani@asu.edu

  Although this person will ask my name, I understand that all inquiries will be kept in the strictest confidence.

- I UNDERSTAND THAT I AM FREE TO WITHDRAW MY CONSENT AND DISCONTINUE MY PARTICIPATION AT ANY TIME.

Date ________________

____

Signature of Subject

APENDIX B

DRIVING SIMULATOR

The Driving Simulation Setup consists of 2 simulation systems. One is a small screen version, where a designer can build his simulation and test it before deploying it on the main, large screen version. The small version is a replica of the main simulator only to a lesser level. Its driving components are similar to that of videogame set.

The Main Simulator is an exact replica of a car with all basic functionalities and the features of the small version simulator. The design tools for the driving simulator are also easy to learn and implement. This study used the main simulator Figure 2 shows the driving simulator setup.

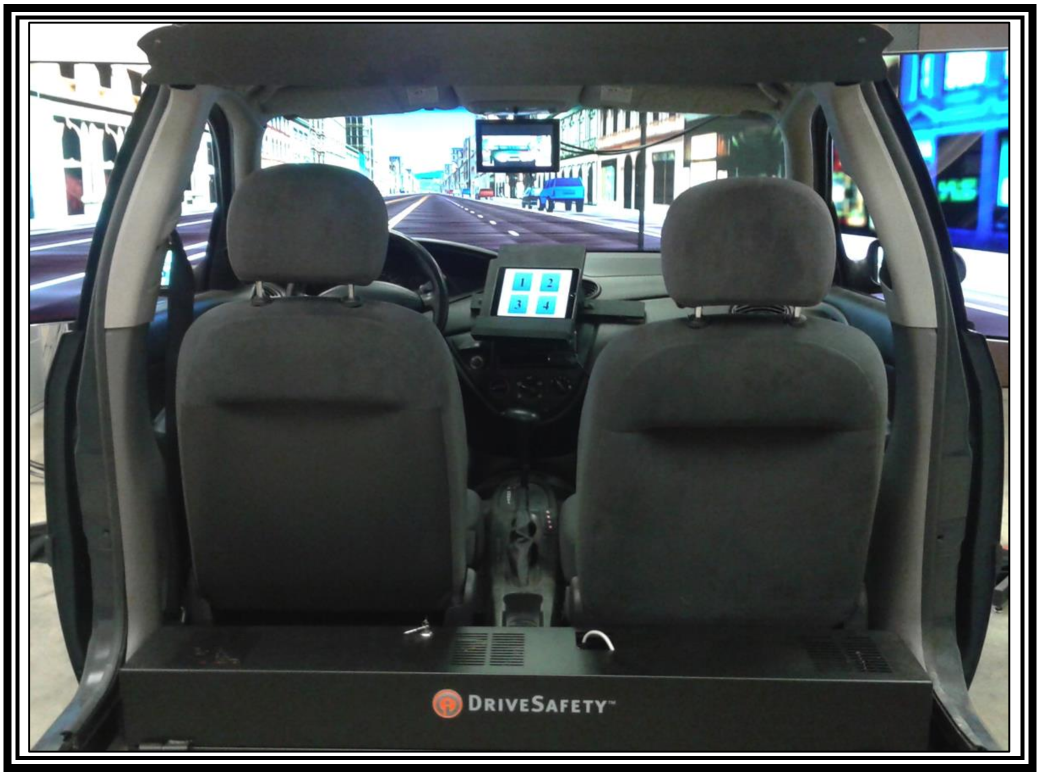


Figure 1: Driving Simulator Setup

To support 2 types of screens – 7” Landscape and 10” Landscape, built a screen holder.

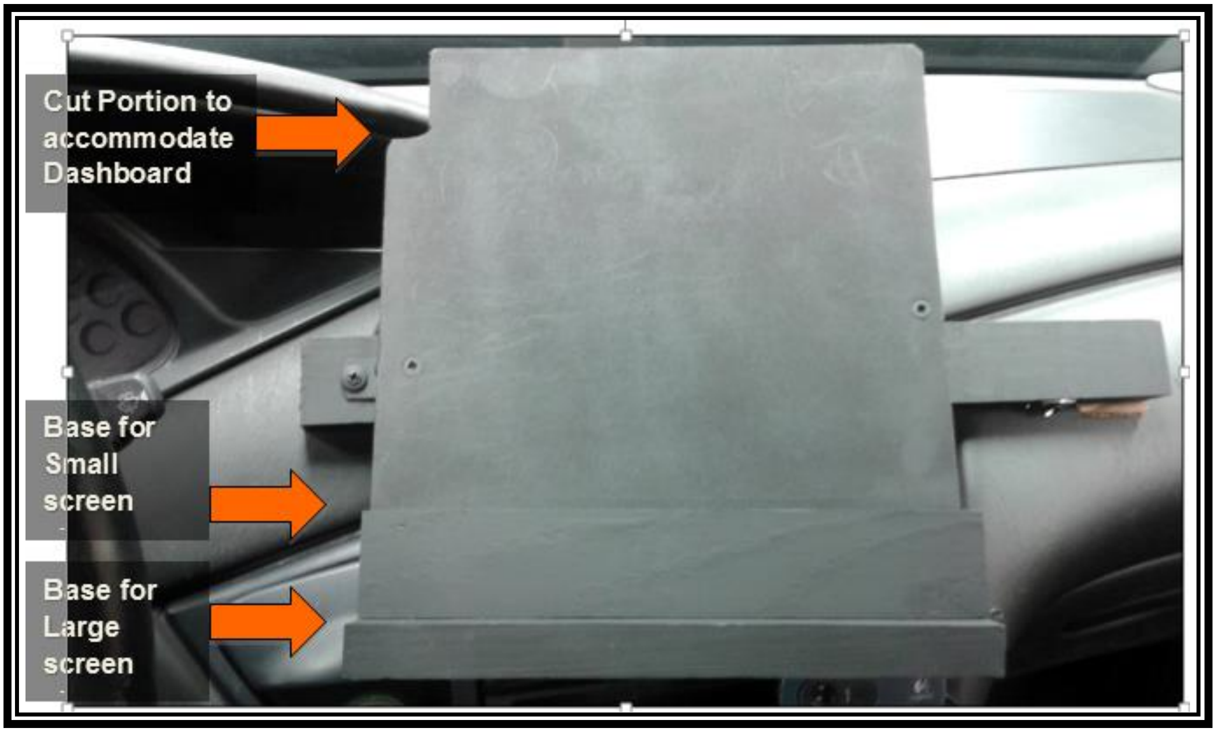


Figure 2: Screen Holder

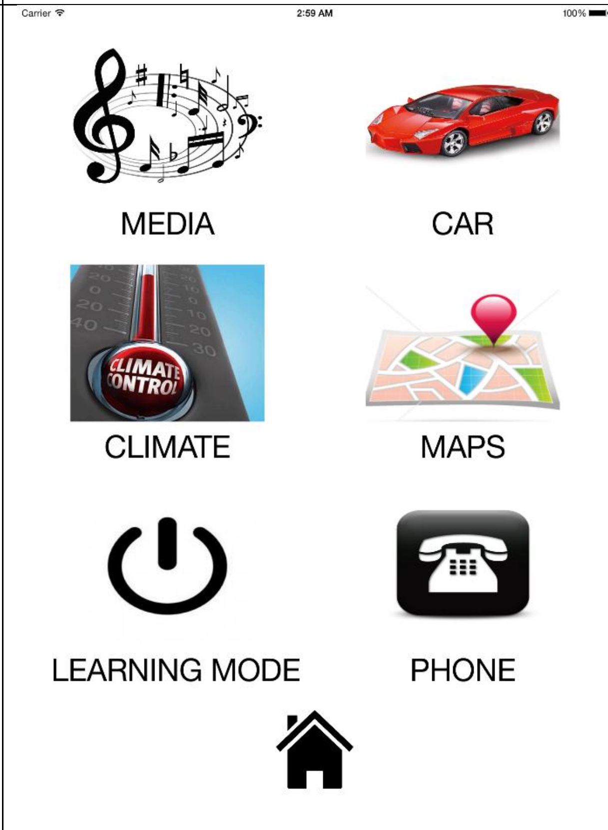
Since, we wanted the screen to be slightly angled to the driver and at a height, so that it does not result in visual distraction. Thus it was affixed at a height that could be seen from the corner of our eye, without losing visual on the road. To angle it towards the driver, the support between the back and front was cut of the different lengths. And a base for the screens to rest on was fixed at the bottom. However, it was observed that at that height, the 10” would obstruct the road view slightly. Hence another beam was attached horizontally at the bottom to support the 10” portrait mode. Thus all screens were at similar lengths, despite their varying sizes. Nailing a toggle bolt to the rear support and a wire used to hold the car dashboard and screen holder together supported this entire structure.

APENDIX C

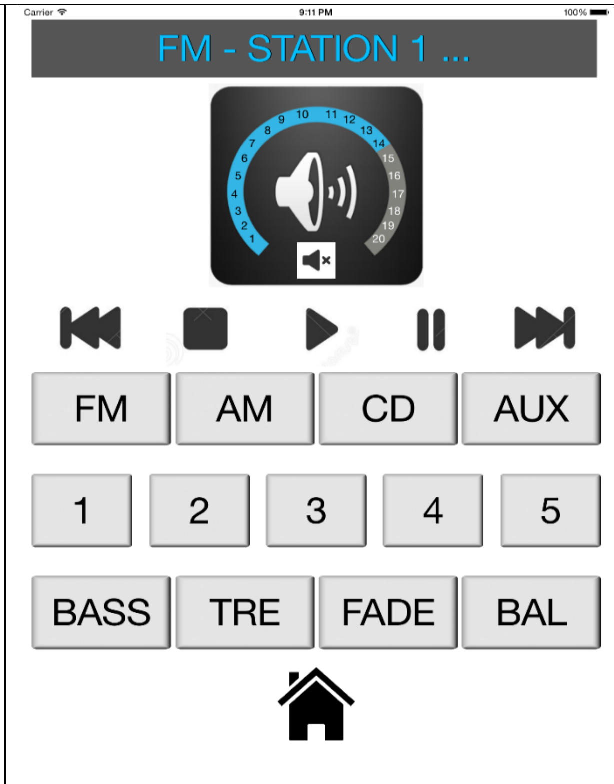
MMIS POTOTYPE

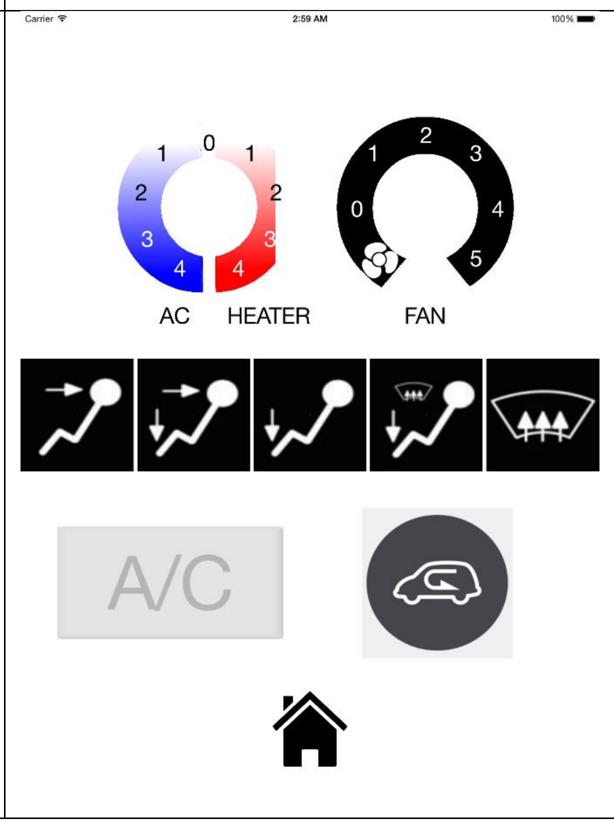
Following is the MMIS design prototype proposed in this study:-

Table 1: MMIS Design Prototype

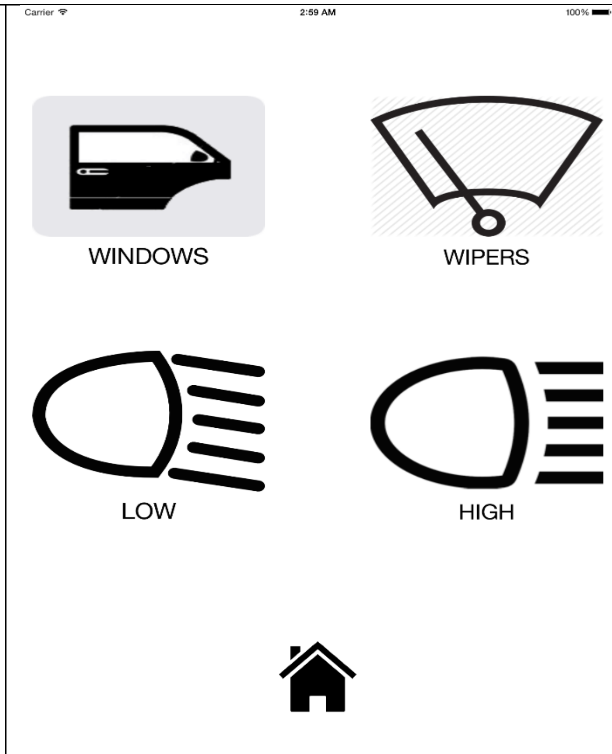
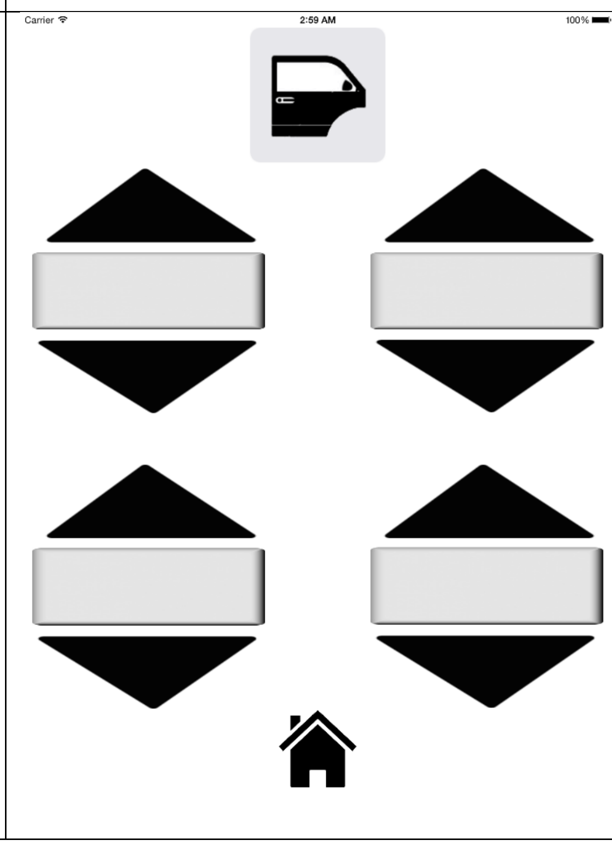
<table>
<tr><th>No.</th><th>Screen Layout</th><th>Description</th></tr>
<tr><td>1</td><td>


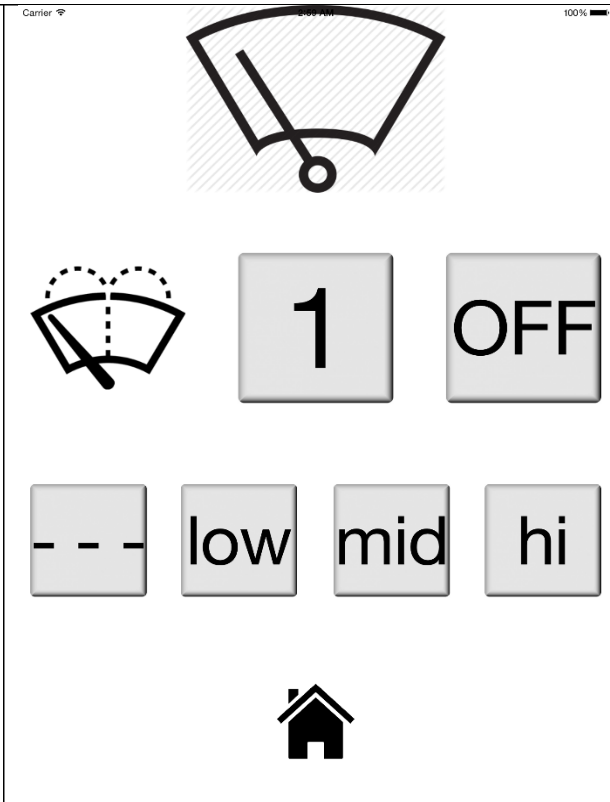
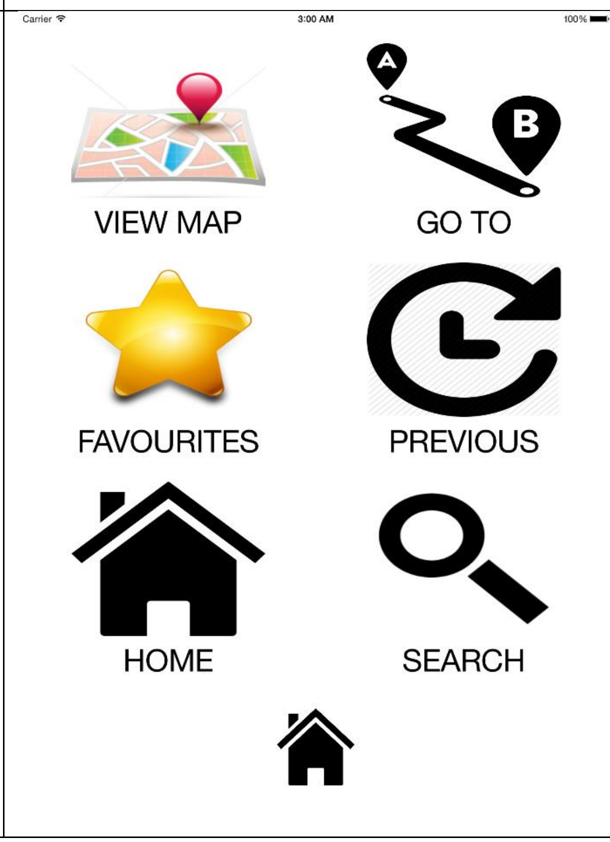
</td><td>Screen:- 1– Home screen
This is the landing screen of the application. Driver can choose any of the icons: Media, Car, Climate, Maps, and Phone for the specific functionality. Learning mode button is to enable or disable learning mode. When learning mode is on, you get talkback and icon titles as features. This can be easily turned off.</td></tr>
</table>

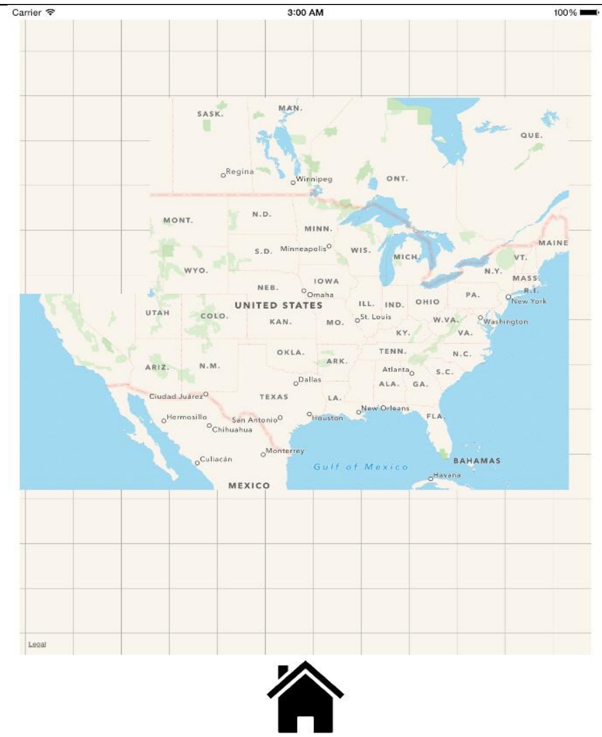
<table>
<tr>
<td>2</td>
<td>
</td>
<td>Screen:- 2– Media Screen

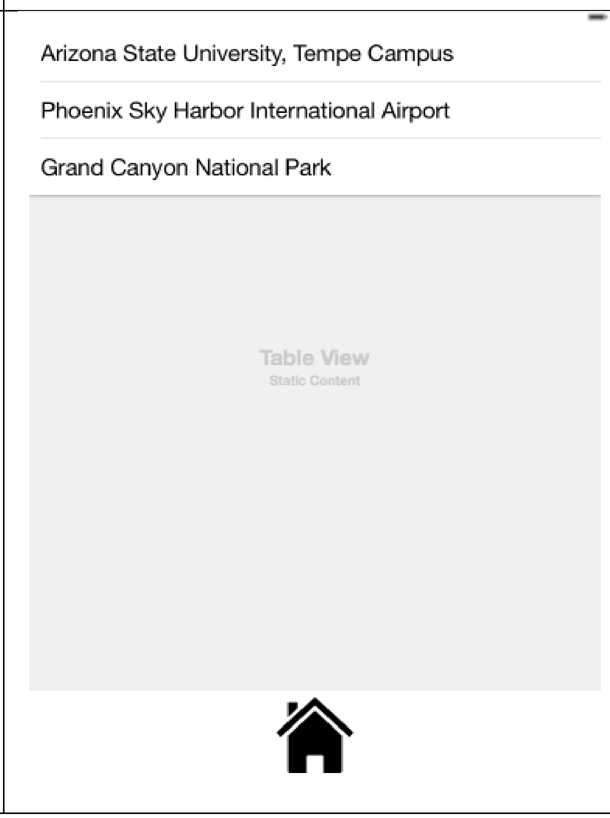
Displays an almost exact replica of the actual radio system in the car. It will have the same functionality as the one given in this design.</td>
</tr>
<tr>
<td>3</td>
<td>
</td>
<td>Screen:- 3– Climate Controls

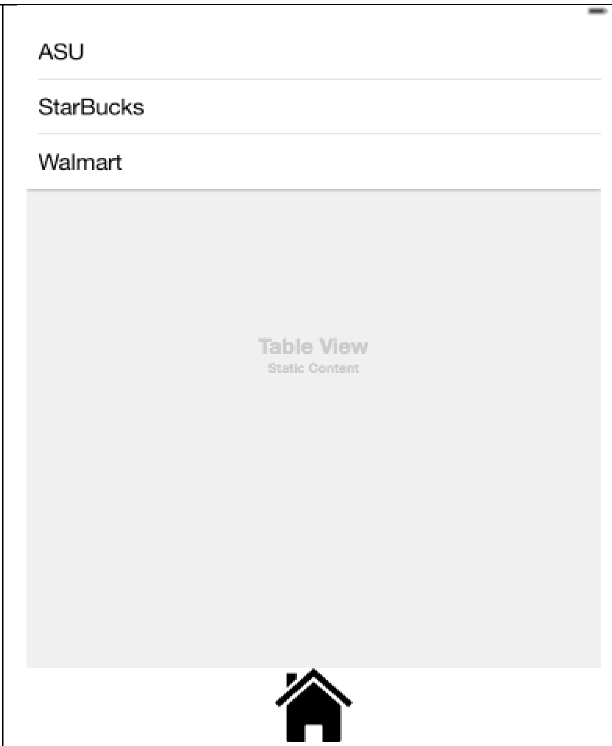
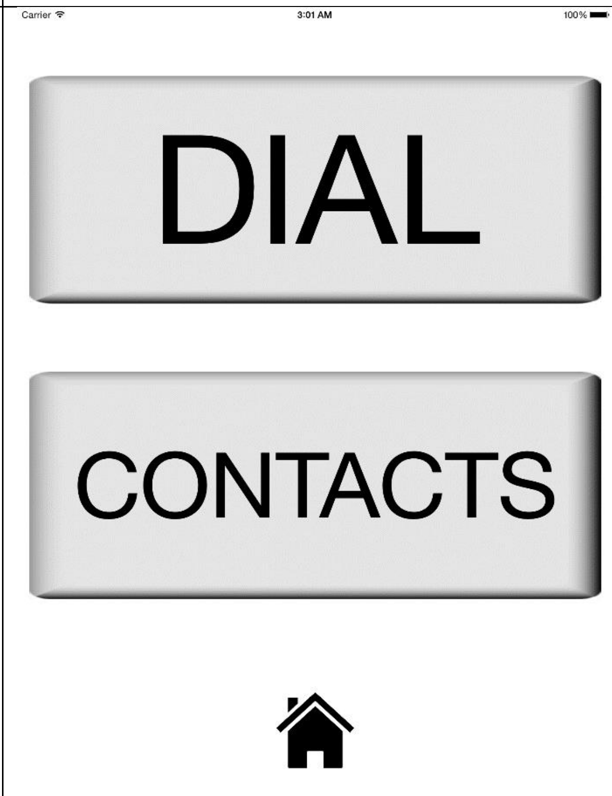
Displays the car climate controls as represented in the car. There are controls for A/C, Heater, FAN and air circulation modes.</td>
</tr>
</table>

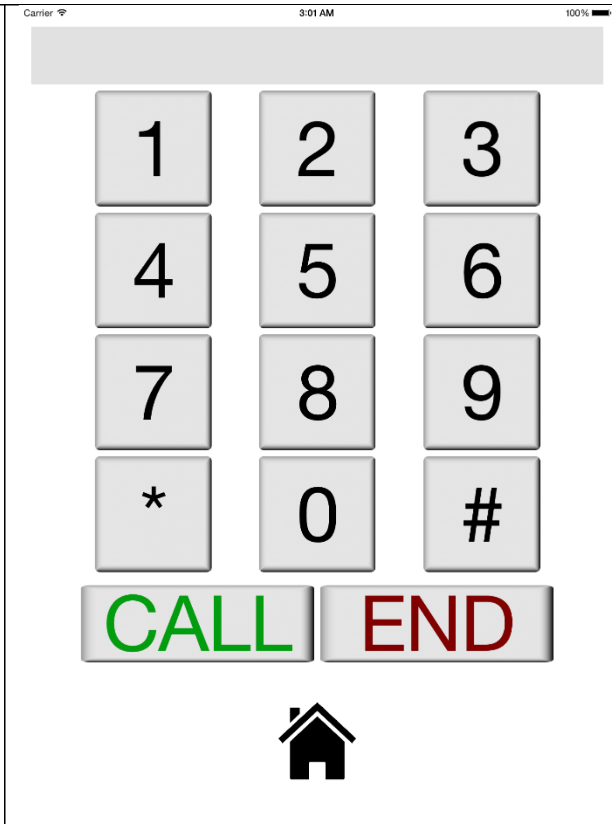
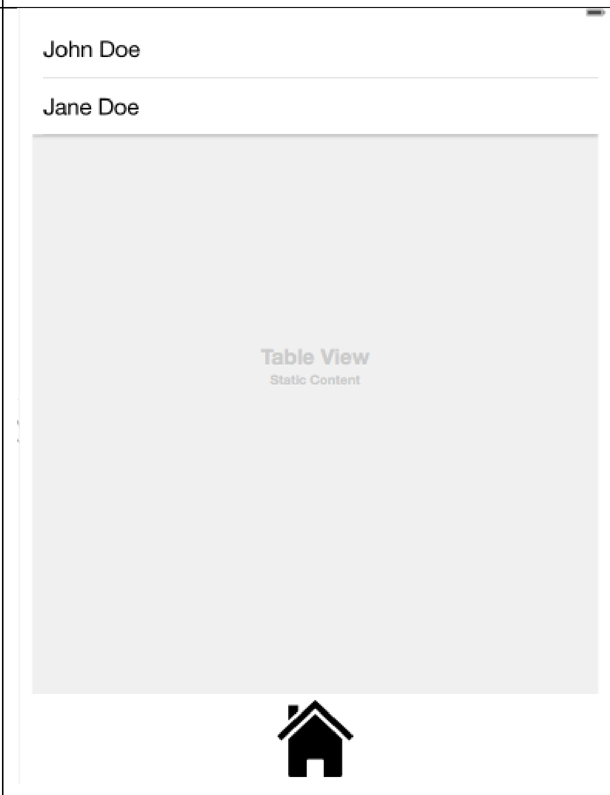
4		Screen:- 4– Car Controls Icons Windows and Wipers lead to another screen with their respective functionality. Low and High buttons are for low and high beam lights of the car.
5		Screen:- 5– Windows Screen Displays the 4 sets of up and down controls of the windows in the car.

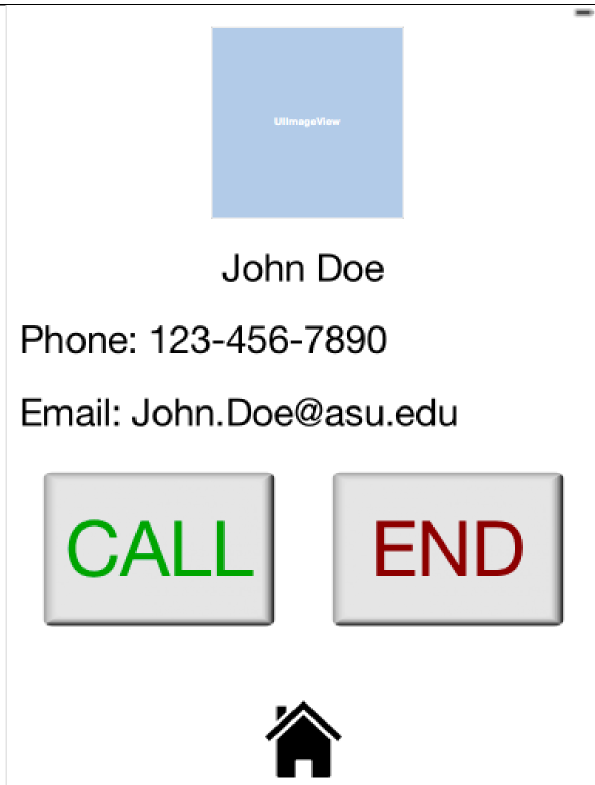
<table>
<tr>
<td>6</td>
<td>
</td>
<td>Screen:- 6– Wipers Screen
Displays various functions related to wipers like water mode, 1, intermittent, low mid high and OFF.</td>
</tr>
<tr>
<td>7</td>
<td>
</td>
<td>Screen:- 7– Map Controls
Displays icons to screens for View Map (Map), Go To (Route guidance from current location to given address), Favorites (All favorite locations by driver), Previous (History), Home (Route guidance from current location to initially set home address) and Search (Displays another screen with options to search).</td>
</tr>
</table>

8		Screen:- 8– View MAP Screen Displays the map with our current location.
9		Screen:- 9– Goto Screen Displays interface to enter the destination address in street #, name, city and state format. The text field at the top displays the address being set. And on clicking go, the screen shown will be the map with route guidance.

<table>
<tr>
<td>10</td>
<td>
</td>
<td>Screen:- 10– Search Screen
Displays 4 options to search – Restaurants, Café, Shopping and Gas Stations. On clicking any of these icons, the map screen will be shown with the selected type of places nearby.</td>
</tr>
<tr>
<td>11</td>
<td>
</td>
<td>Screen:- 11– Previous Screen
Displays the history, that is all previously visited, searched or used locations.</td>
</tr>
</table>

12		Screen :-12 – Favorite Screen Displays a list of all locations marked as favorite by driver. The locations can be marked by visiting the view map screen.
13		Screen:- 13 – Phone Screen This screen has 2 options – Dial and contacts. One can either dial or select a contact from the list to call.

14		Screen:- 14 – Dial Screen Displays a number pad with text field at the top displaying the currently typed phone number. You can call the number and to end the same call click on the end.
15		Screen:- 15 – Contacts Screen Displays all contacts present in the directory.

<table>
<tr>
<td>16</td>
<td>
</td>
<td>Screen :- 16 – Display Contact Screen
Displays details like – Full Name, Image, Phone number and email id of the person selected. There is an option to call the person and the end the call here as well.</td>
</tr>
</table>

APENDIX D

DATA COLLECTED

[Consult Attached File]